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PHOSPHATE REMOVAL BY ACTIVATED SLUDGE. AMENABILITY STUDIES AT BALTIMORE, MARYLAND

M. R. Scalf, et al

Robert S. Kerr Water Research Center
Ada, Oklahoma

June 1969

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PHOSPHATE REMOVAL BY ACTIVATED SLUDGE

Amenability Studies at Baltimore, Maryland

by

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ABSTRACT

Phosphate removal by sorption on activated sludge was investigated in pilot and plant scale at the Baltimore, Maryland, Back River Sewage Works. These studies revealed that the activated sludge plant was obtaining high phosphorus removal under conditions similar to those found in the San Antonio Rilling Plant. Pilot investigations were made on the amenability of the waste and activated sludge to phosphate removal. The effects of suspended solids and dissolved oxygen concentrations in the mixed liquor, phosphate additions, oxygen demanding substrate additions, and the addition of aluminum, iron, and magnesium salts on phosphate removal were determined and found to agree with previous information. The waste and sludge were very amenable to phosphate removal.

Because of the amenability and the design and operation of the facilities, the activated sludge plant at the Baltimore Back River Sewage Works is highly suited for full scale research investigations on phosphate removal.

INTRODUCTION

This report describes investigations at the Back River Sewage Works of Baltimore, Maryland, in a continuing research program concerned with the removal of phosphate from municipal sewage by the activated sludge process. Field research conducted at San Antonio, Texas, established that high removals of orthophosphate were accomplished in the aeration tanks by sorption from the liquid to the mixed liquor suspended solids. The efficiency of the removal process was found at San Antonio to be controlled by the operational and design parameters including: aeration detention times, air supplied, mixed liquor suspended solids concentration, BOD load, phosphate load, rapid solid-liquid separation, minimum solids detention time in the final clarifiers and separate disposal of phosphate concentrates.[1],[2]

The purposes of the amenability studies conducted were:

1. To determine if biological phosphate uptake is feasible in municipalities of various geographical locations, populations served, and sewage characteristics by pilot and plant investigations.

2. To locate six or more activated sludge plants in various geographical regions to be used for demonstration of biological phosphate removal by operation in accordance with parameters identified at San Antonio.

3. To locate one activated sludge plant of suitable design and operational flexibility for use as a full scale research plant to further specify, define, and optimize the biological phosphate removal process.

4. To verify on pilot scale that biological phosphate removal can be controlled by the parameters identified at San Antonio and/or isolate and identify additional controlling parameters.

---

[1] Priesing, C. P., Witherow, J. L., Lively, L. D., Scalf, M. R., DePrater, B. L., Myers, L. H., "Phosphate Removal by Activated Sludge--Pilot Research," 40th Annual Conference, Water Pollution Control Federation, New York, New York. October 11, 1967.

[2] Priesing, C. P., Witherow, J. L., Lively, L. D., Scalf, M. R., DePrater, B. L., Myers, L. H., "Phosphate Removal by Activated Sludge--Plant Research," 40th Annual Conference, Water Pollution Control Federation, New York, New York. October 11, 1967.

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Aerated jugs of mixed liquor have been previously shown to simulate an aeration tank. Aerated jugs circumvent many of the limitations exerted by normal operational characteristics in activated sludge plants, such as control of aeration rate, sewage flow, suspended solids concentration, and phosphate and BOD loadings. Sludge solids and waste from various points in the secondary system may be conveniently studied. Detention time of the mixed liquor in the aerated jug system is rigidly controlled. For these reasons, the method was selected as the means of testing the amenability of the waste and activated sludge to phosphate removal.

By deliberate variation of the operational parameters, the conditions for sludge response and maximum phosphate removal can be established. These amenability studies will indicate those waste and activated sludges most readily adaptable and, in conjunction with plant investigations, will aid in specifying operational levels, design changes, or time for sludge adaptability necessary to attain phosphate removal in the full-scale plant.

Experimental Procedures

Plant Analysis

The plant was studied to determine pertinent design and operational characteristics. Programs of plant sampling and tracer studies were carried out in addition to jug studies to determine plant performance.

Plant records were examined for type and frequency of sewage flow, plant loading of BOD, suspended solids, and orthophosphate concentrations, analyses of chemical and physical parameters, and performance characteristics. Typical data are presented in Appendix II. Plant personnel were questioned about sampling practices, analytical procedures, anomalies of wastes being treated, and peculiarities of operational control. The schedules for wasting raw and activated sludges were determined. Disposal methods of waste activated sludge, primary sludge, digester supernatant, sludge thickener supernatant, drying bed underflow, and other waste streams were studied in anticipation of auxiliary, inhibitory, or latent effects on the phosphate removal process.

Tracer studies were conducted using Rhodamine WT dye on aeration tanks and final clarifiers to determine hydraulic characteristics such as detention, short circuiting, and degree of longitudinal mixing.

Grab samples were collected throughout the plant to determine the phosphate levels and degree of removal. These samples were analyzed for concentration of orthophosphate and, occasionally, total phosphates and suspended solids. Chemically fixed samples were returned to the

Robert S. Kerr Water Research Center at Ada, Oklahoma, for total phosphate and COD. The sample sources were raw sewage, primary effluent, return sludge, aeration tank influent, aeration tank effluent, and final effluent. Occasionally, supernatant samples were taken from digestion tanks and sludge thickeners. Dissolved oxygen measurements were made throughout the plant in conjunction with the sampling program. When these studies indicated that phosphate was being removed, more detailed sampling on a slug flow basis was undertaken to specify the magnitude of removal.

Aeration Jug Studies

Return sludge or mixed liquor from various points in the seconday system was mixed with primary effluent or raw sewage to obtain the desired range of suspended solids concentration. The mixtures were prepared in five-gallon polyethylene jugs for subsequent aeration.

A portable air compressor was used as the air supply. Air was delivered through a manifold containing individual needle valves and rotometers for each jug. Polyethylene tee fittings were used as diffusers. The air flow was maintained constant throughout the experiment, except where noted.

The dissolved oxygen content and the temperature of the mixed liquor were monitored several times during each run.

Samples were withdrawn from the jugs usually at half-hour or hourly intervals. Preceding sample collection, approximately 200 ml of mixed liquor was siphoned through the Tygon withdrawal tube for purging and returned to the original jug. A volume of 100 ml was sufficient for orthophosphate analysis, and 250 ml was taken when additional analyses were planned.

RESULTS AND DISCUSSIONS

Plant Characteristics

The Back River Sewage Works at Baltimore, Maryland, is composed of one primary treatment system and two secondary treatment systems. The trickling filter system treats about 130 MGD of the effluent from the primary system, and the conventional activated sludge system treats the remaining 20 MGD. Phosphate removal investigations conducted at Baltimore were primarily concerned with the activated sludge portion of the plant. The total plant layout is shown in Figure No. 1, and the activated sludge unit is detailed in Figure No. 2.

The activated sludge process consists of two end-around aeration tanks and two final clarifiers. Flow to these units is held constant at about 20 MGD of primary effluent plus 4 MGD of return sludge. Mixed liquor suspended solids ranged from 1700 to 3600 mg/l during these studies but usually fluctuated between 1700 and 2300 mg/l. Air supplied to the two aeration tanks was approximately 23 million cubic feet per day (MCFD) or 1.1 cubic foot of air per gallon of sewage treated. This air rate is sufficient to maintain a normal dissolved oxygen residual in the effluent end of the aeration tanks of about 5 or 6 mg/l and in the final clarifiers of about 3 mg/l.

The primary effluent normally has a BOD of about 200 mg/l and a suspended solids concentration of 130 mg/l. The final effluent from the activated sludge system contained about 10 mg/l BOD and suspended solids, giving removals of over 90 percent.

The primary effluent received by the activated sludge system is a product of seven primary clarifiers which serve the entire Back River Sewage Works. The influent to the primary clarifiers is a combination of raw sewage plus digester supernatant, sludge elutrient from the vacuum filters, waste activated sludge, settled sludge from the humus (settling) tanks, and effluent from some uncovered sludge settling tanks. These additions to the raw sewage are made on irregular schedules and at variable rates, and measurements are not always made of the volumes. The only apparent difference between primary effluent treated by the activated sludge and trickling filter systems is an additional screening of the activated sludge influent.

All of the final effluent from the activated sludge and about one-half from the trickling filter system is purchased by the Bethlehem Steel Company. The unsold effluent is discharged after chlorination to the Back River. The waste sludge from both systems eventually passes through a vacuum filter and a sludge dryer. The dried sludge is then dumped on the grounds around the plant and given to anyone who will haul it away.

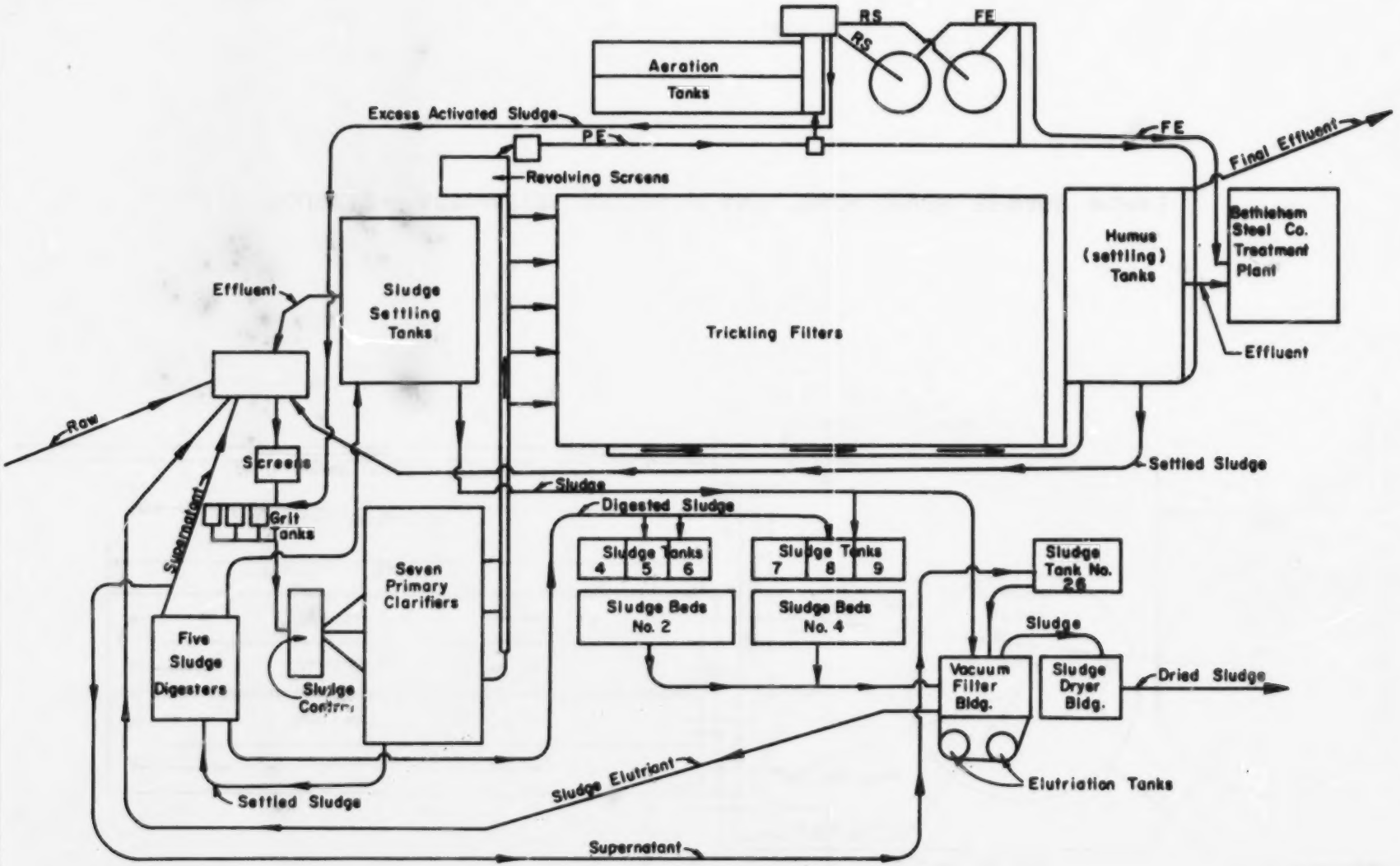

FIGURE 1 – BACK RIVER SEWAGE WORKS, BALTIMORE, MARYLAND

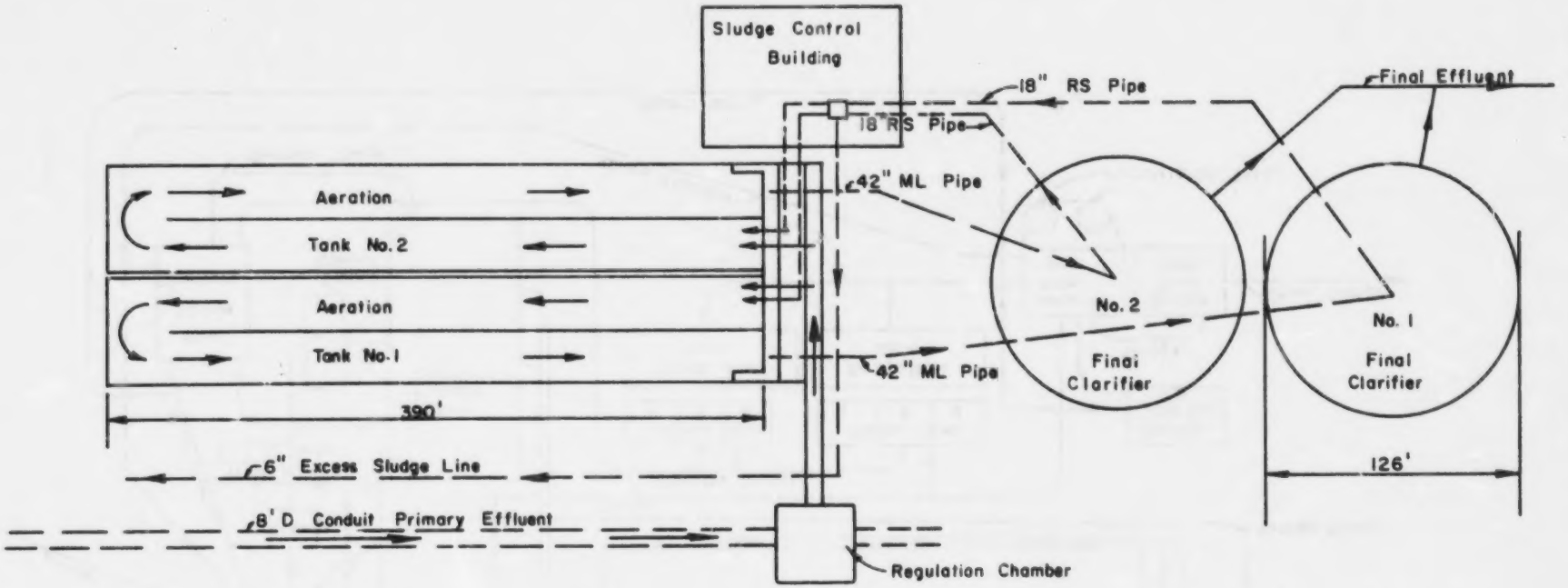

FIGURE 2 – ACTIVATED SLUDGE PLANT, BACK RIVER SEWAGE WORKS

Detention Studies

Tracer studies were conducted on the aeration tanks and final clarifiers on April 5 and 14, 1967. Rhodamine WT dye was used as a tracer to determine the hydraulic characteristics of the aeration tanks and final clarifiers.

1. Aeration Tanks

Five liters of 20 percent Rhodamine WT solution were introduced into the head end of both 2.6-million gallon aeration tanks at 11:00 a.m. on April 5, 1967. The dye concentrations were monitored at the half points and at the effluent ends. The flow rates in Aeration Tanks Nos. 1 and 2 were essentially constant at 12.4 and 13.7 MGD, respectively, resulting in theoretical displacement times of 5.0 and 4.5 hours.

Figure No. 3 presents dye concentration at the effluent end of the aeration tanks. Both tanks exhibited almost normal distribution curves with modal detention times within 30 minutes (10 percent) of the theoretical displacement times. These distribution curves indicate hydraulic conditions closer to plug flow than in any other aeration tanks yet studied by this Center.

In addition to a large length to width ratio (25:1), the air transfer system is probably significant to plug flow conditions in the aeration tanks. Unlike most of the tanks observed during previous phosphate studies, Baltimore uses flat diffusion plates set into the bottom of the tank and extending along one wall the complete length of the tank. These plates range in step-wise fashion from coarse plates at the inlet end of the tanks to very fine plates at the outlet ends. Most other treatment plants visited use diffusion cubes located one to three feet above the floor and spaced intermittently along the length of the tank.

2. Final Clarifiers

Dye studies were conducted on both final clarifiers. On April 13, 1967, two (2) liters of 20 percent Rhodamine WT dye were introduced into the center well of each 1.3-million gallon final clarifier. The final effluent of each clarifier and the combined return sludge were monitored for dye concentrations.

Figure No. 4 presents dye concentrations versus time for the final effluents and return sludge. Final Clarifier No. 2 generally showed better retention with a modal detention time of 60 percent of theoretical displacement time compared to about 30 percent modal detention in Clarifier No. 1.

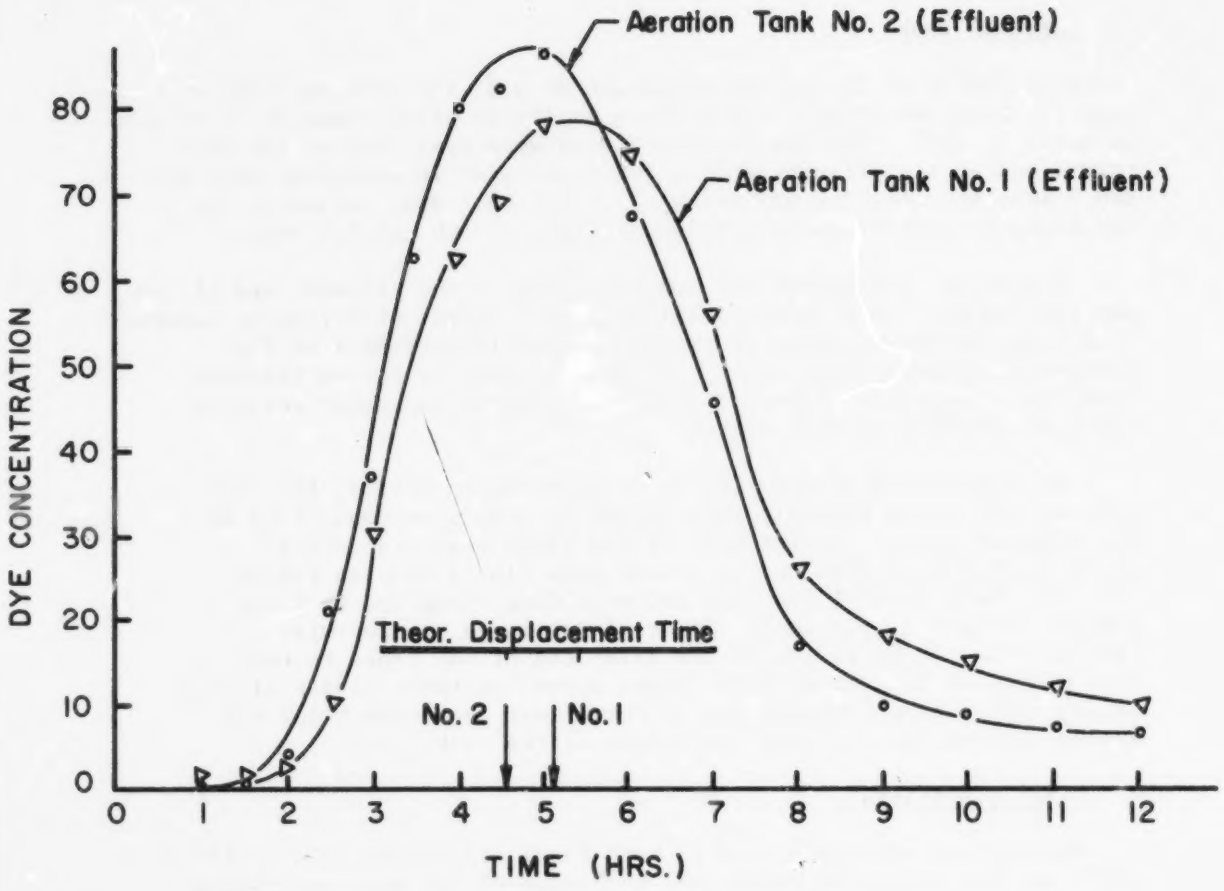

FIGURE 3 – DYE DETENTION IN AERATION TANKS

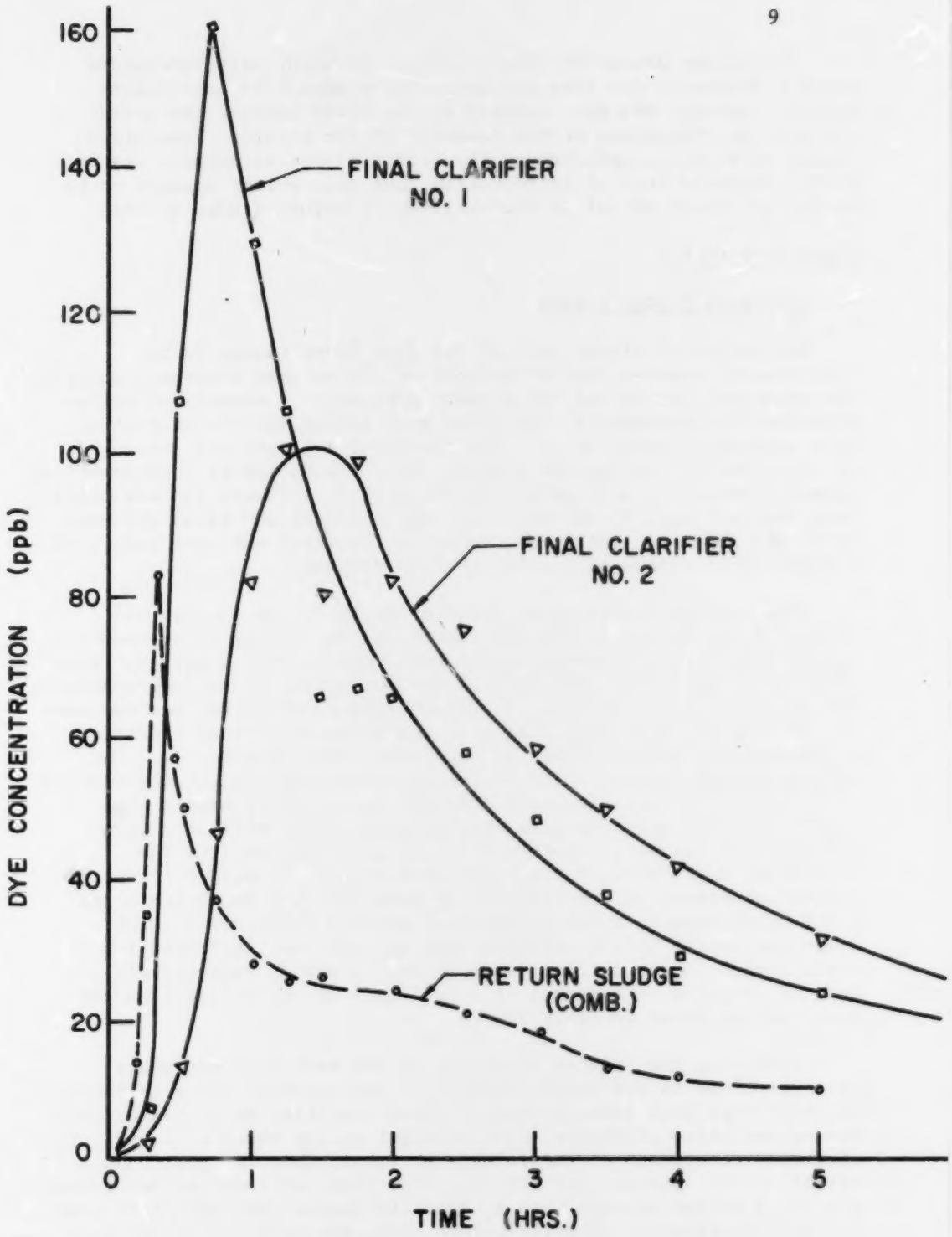

FIGURE 4 — DYE DETENTION IN FINAL CLARIFIERS

The sludge detention time could not be accurately determined because Rhodamine dye does not appreciably adsorb to particulate matter; however, the dye trapped in the voids between the solids did give an indication of the behavior of the sludge. Some mixed liquor short circuited through the return sludge withdrawal system within one-half hour of introduction, but this volume appears to be an insignificant amount of the overflow or return sludge volumes.

Plant Performance

1. Activated Sludge System

The activated sludge unit of the Back River Sewage Works consistently removes over 95 percent of the soluble phosphate entering the secondary system via the primary effluent. A summary of orthophosphate measurements in the plant made during the two-week study is presented in Table No. 1. All the plant analyses are presented in Table No. 2. During the studies, the orthophosphate concentrations ranged from 5.3 to 12.0 mg/l P in the primary effluent and was usually less than 1.0 mg/l in the aeration tank effluent and final effluent. Total phosphate concentrations found in the final effluent indicated removal efficiencies of greater than 90 percent.

One notable exception occurred on April 7. When waste was collected at 12:00 noon for Jug Experiment No. 3, the orthophosphate concentration in the return sludge was found to be 535 mg/l P. This resulted in very high (120 mg/l P) concentrations of orthophosphate in the aeration jugs. A check of orthophosphate concentrations was made on combined aeration tank influents and effluents, final clarifier effluents, and return sludge at 6:00 p.m. (see Table No. 1). The orthophosphate concentration in the return sludge was greatly reduced to 75 mg/l. The aeration tank influent was slightly higher than normal, and the aeration tank effluents and final effluents were significantly higher. Another check of grab samples from the individual tanks at 7:00 p.m. indicated a high (33 mg/l P) level of soluble phosphate in the effluent of Aeration Tank No. 2 and a low (<0.1 mg/l) amount in the effluent of Aeration Tank No. 1. The dissolved oxygen in the aeration tank at 7:00 p.m. indicated 1.5 and 2.5 mg/l in the effluent ends of Nos. 1 and 2, respectively. This is compared to a normal of 5 to 7 mg/l in the effluent end of each tank as shown in Table No. 2.

Following the initial discovery of the very high phosphate concentrations in the return sludge, it was learned that a malfunction of the sludge withdrawal system of Final Clarifier No. 2 had allowed the accumulation of sludge since midnight or for about 12 hours. This permitted desorption of the soluble phosphate from the particulate matter to the interstitial liquid. (The final effluent evidently was not yet affected at noon when a composite sample indicated less than 1.0 mg/l phosphate.) Shortly before noon, the malfunction was repaired,

Table No. 1

PLANT MONITORING SUMMARY

Orthophosphate (mg/l P)

Date - Time 1967	Raw [1]	RS [2]	PE [3] Ac	Tank #1 AT [4] in	Tank #1 AT [5] 1/2	Tank #1 AT [6] out	Tank #1 FE [7] 1	Tank #2 AT in	Tank #2 AT 1/2	Tank #2 AT out	Tank #2 FE 2	Composite AT in	Composite AT out	Composite FE	Trickling Filter Plant PE [8] TF	Trickling Filter Plant FE [9] TF	Trickling Filter Plant Tot. [10] Pl. Eff.
4/3 - 1:30 P	7.5	9.7	9.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3:30 P	6.7	14.7	2.0	32.4	3.0	<0.1	0.1	29.0	38.5	1.0	<0.1	--	--	--	--	--	--
4/4 - 9:15 A	--	31.6	7.8	26.5	4.6	0.5	<0.1	31.0	25.5	0.8	0.7	--	--	--	7.8	3.5	--
3:00 P	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.5	10.2	--
5:00 P	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.0	11.2	--
4/5 - 4:40 P	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.2	11.5	--
3:00 P	--	16.6	5.3	22.4	0.5	<0.1	<0.1	23.3	25.6	<0.1	<0.1	--	--	--	--	--	--
4/6 -12:15 P	4.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2:30 P	--	13.0	7.0	18.6	--	--	--	--	--	--	--	--	--	--	--	--	--
3:30 P	--	14.7	6.7	23.5	--	--	--	--	--	--	--	--	--	--	--	--	--
5:00 P	--	--	--	--	<0.1	--	--	--	--	--	--	--	--	--	--	--	--
6:00 P	--	--	--	--	<0.1	--	--	--	--	--	--	--	--	--	--	--	--
7:30 P	--	--	--	--	--	<0.1	--	--	--	--	--	--	--	--	--	--	--
8:30 P	--	--	--	--	--	<0.1	--	--	--	--	--	--	--	--	--	--	--
9:00 P	--	--	--	--	--	--	<0.1	--	--	--	--	--	--	--	--	--	--
4/7 -12:00 N	--	535	7.6	--	--	--	--	--	--	--	--	--	--	0.3	--	--	--
6:00 P	--	75	8.7	--	--	--	--	--	--	--	--	34.0	14.5	9.7	--	--	--
7:00 P	--	--	--	38.0	34.0	<0.1	--	59.0	40.0	33.0	--	--	--		--	--	--
4/10-11:00 A	--	6.0	12.0	--	--	--	--	--	--	--	--	--	--	0.1	--	--	--
12:30 P	--	13.0	9.0	--	--	--	--	--	--	--	--	--	--	<0.1	--	--	--
5:15 P	6.4	--	1.0	--	--	--	--	--	--	--	--	35.0	0.6	0.1	--	13.8	11.2
4/11- 2:00 P	5.3	8.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2:00 P	--	--	8.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5:00 P	--	--	--	--	--	--	--	--	--	--	--	--	--	0.6	--	--	--
4/12- 5:00 P	--	9.4	9.6	--	--	--	0.1	--	--	--	0.1	29.1	0.4	--	--	--	--
4/13-10:00 A	4.5	--	--	--	--	--	--	--	--	--	--	--	--	--	8.9	10.0	12.0
11:00 A	--	8.5	--	--	--	--	--	--	--	--	--	21.5	<0.1	--	--	--	--
4/14- 9:00 A	2.0	12.5	7.0	--	--	--	--	--	--	--	--	25.0	<0.1	<0.1	7.6	10.4	11.8
1:00 P	8.4	37.5	--	--	--	--	--	--	--	--	--	33.0	0.3	0.1	15.8	9.2	11.0

1/ Raw sewage to the plant.
2/ Return sludge from final clarifiers.
3/ Primary effluent to activated sludge system.
4/ Mixed liquor from influent end of aeration tank.
5/ Mixed liquor at 1/2 point in aeration tank.
6/ Mixed liquor at effluent end of aeration tank.
7/ Final effluent from No. 1 clarifier.
8/ Primary effluent at influent to trickling filters.
9/ Trickling filter effluent.
10/ Total plant effluent to river.

Table No. 2

PLANT MONITORING DATA, APRIL 3-14, 1967

Sample	Date	Time	DO (mg/l)	Ortho Phosphate (mg/l P)	Temp °C	pH	Carbon Total (mg/l)	Carbon Inorganic (mg/l)	Total Hardness (mg/l $CaCO_3$)	Total Phosphate (mg/l P)	Total Plate Count (Count/ml)
Raw	4/3	1:30 pm	-	7.5	-	-	-	-	104	-	-
		3:30 pm	-	6.7	-	-	-	-	-	-	-
	4/6	12:15 pm	-	6.0	-	-	-	-	-	-	-
	4/10	3:15 pm	-	6.6	-	-	-	-	-	-	-
	4/11	2:00 pm	-	5.3	-	-	-	-	-	-	2.6×10^5
	4/13	10:00 am	-	4.5	-	-	86	81	-	-	-
	4/14	9:00 am	-	2.0	-	-	82	67	-	12.3	-
		1:00 pm	-	8.6	-	-	109	84	-	-	-
E-5	4/3	12:30 pm	7980	-	-	-	-	-	-	-	-
		1:30 pm	-	6.7	-	-	-	-	-	-	4.1×10^6
		3:30 pm	-	14.7	-	-	-	-	-	-	-
	4/6	9:15 am	9930	31.6	-	-	-	-	138	-	-
	4/5	3:00 pm	-	16.6	-	-	-	-	-	-	-
	4/6	2:30 pm	8510	13.0	-	-	76	62	-	380	2.0×10^6
		3:30 pm	7350	14.7	-	-	78	60	-	362	-
	4/7	12:00 n	-	535	-	-	-	-	-	-	-
		6:00 pm	-	75	-	-	-	-	-	-	-
	4/10	11:00 am	8450	6.0	-	-	-	-	-	-	-
		12:30 pm	8870	13.0	-	-	76	35	-	-	-
	4/11	2:00 pm	-	8.8	-	-	90	45	-	-	3.0×10^5
	4/12	5:00 pm	-	9.4	-	-	-	-	-	-	-
	4/13	11:00 am	-	8.5	-	-	103	61	-	-	-
	4/14	9:00 am	7430	12.5	-	-	91	45	-	-	-
		1:00 pm	-	37.5	-	-	89	44	-	-	-
PE_{NE}	4/3	1:30 pm	-	9.5	-	-	-	-	-	-	5.3×10^5
		3:30 pm	-	9.0	-	-	-	-	-	-	-
	4/6	9:15 am	91	7.8	-	-	-	-	112	-	-
	4/5	3:00 pm	-	5.3	-	-	-	-	-	-	-
	4/6	2:30 pm	166	7.0	14.0	0.6	136	100	-	14.0	3.0×10^6
		3:30 pm	150	6.7	-	-	136	100	-	12.5	-
	4/7	12:30 n	165	7.6	-	-	-	-	-	-	-
		6:00 pm	-	8.7	-	-	-	-	-	-	-
	4/10	11:00 am	210	12.0	-	-	-	-	-	-	-
		12:30 pm	207	9.0	-	-	134	134	-	-	-
		5:15 pm	-	11.0	-	-	-	-	-	-	-
	4/11	2:00 pm	-	8.3	-	-	102	138	-	-	4.6×10^5
	4/12	5:00 pm	-	9.6	-	-	-	-	-	-	-
	4/14	9:00 am	-	7.0	-	-	132	106	-	11.0	-
		1:00 pm	-	-	-	-	140	148	-	10.6	-
PE_{EE}	4/6	9:15 am	-	7.8	-	-	-	-	91	-	-
		3:00 pm	-	7.5	-	-	-	-	-	-	-
		5:00 pm	-	8.0	-	-	-	-	-	-	-
	4/5	4:40 pm	-	6.2	-	-	-	-	-	-	-
	4/13	10:00 am	-	8.9	-	-	136	126	-	-	-
	4/14	9:00 am	-	7.6	-	-	147	122	-	-	-
		1:00 pm	-	13.6	-	-	202	167	-	-	-
ASP1 (in)	4/3	12:30 pm	2140	-	-	-	-	-	-	-	93.0×10^5
		3:30 pm	-	32.6	-	-	-	-	-	-	-
	4/6	9:15 am	2180	26.5	-	-	-	-	112	-	-
	4/5	3:00 pm	-	22.6	-	-	-	-	-	-	-
		5:30 pm	-	-	15	0.5	-	-	-	-	-
	4/6	2:30 pm	1580	18.6	15	0.5	66	50	-	90.0	1.0×10^6
		3:30 pm	3020	23.5	-	-	-	-	-	83.8	1.0×10^6
		4:30 pm	-	-	13.5	0.5	-	-	-	-	-
		7:30 pm	-	-	13.5	0.5	-	-	-	-	-
	4/7	7:00 pm	-	16.0	13.0	0.5	-	-	-	-	-
ASP1 (1/2)	4/3	3:30 pm	-	3.0	-	-	-	-	-	-	97.6×10^5
	4/6	9:15 am	-	6.6	-	-	-	-	100	-	-
	4/5	3:00 pm	-	0.5	-	-	-	-	-	-	-
		5:30 pm	-	-	15	1.6	-	-	-	-	-
	4/6	2:30 pm	-	-	15	3.2	-	-	-	-	-
		4:30 pm	-	-	15	4.0	-	-	-	-	-
		5:00 pm	2330	<0.1	-	-	75	29	-	87.5	-
		6:00 pm	-	<0.1	-	-	77	31	-	90.2	-
		7:30 pm	-	-	15.5	3.2	-	-	-	-	-
	4/7	7:00 pm	-	14.0	15.0	1.0	-	-	-	-	-

*These data are from 1:30 p.m. samples.

NOTE: This data not all inclusive; some data from Aeration Tank and Jug Comparison not included.

Sample	Date	Time	DO (mg/l)	Ortho Phosphate (mg/l P)	Temp °C	pH	Carbon Total (mg/l)	Carbon Inorganic (mg/l)	Total Hardness (mg/l $CaCO_3$)	Total Phosphate (mg/l P)	Total Plate Count (Count/ml)
ASP1 (cont)	4/3	1:30 pm	-	-	-	-	-	-	104	-	2.3×10^5
	4/5	3:30 pm	-	<0.1	-	-	-	-	-	-	-
	4/6	9:15 am	-	0.5	-	-	-	-	96	-	-
	4/5	3:00 pm	-	<0.1	-	-	-	-	-	-	-
		5:30 pm	-	-	15	6.5	-	-	-	-	-
	4/6	2:30 pm	-	-	15.5	7.2	-	-	-	-	-
		4:30 pm	-	-	15.5	7.3	-	-	-	-	-
		7:30 pm	1000	<0.1	13.5	7.8	67	63	-	85	-
		8:30 pm	-	<0.1	-	-	72	38	-	-	-
	4/7	7:00 pm	-	<0.1	13.0	1.5	-	-	-	-	-
		12:30 pm	2040	-	-	-	-	-	-	-	-
ASP2 (in)	4/3	3:30 pm	-	29.0	-	-	-	-	-	-	42.2×10^6
	4/6	9:15 am	2630	31.0	-	-	-	-	132	-	-
	4/5	3:00 pm	-	23.3	-	-	-	-	-	-	-
		5:30 pm	-	-	15	0.4	-	-	-	-	-
	4/6	2:30 pm	-	-	14.5	0.4	-	-	-	-	-
	4/7	7:00 pm	-	14.0	13.0	0.3	-	-	-	-	-
ASP2 (1/2)	4/3	3:30 pm	-	38.5	-	-	-	-	-	-	49.6×10^5
	4/6	9:15 am	-	25.5	-	-	-	-	118	-	-
	4/5	3:00 pm	-	25.6	-	-	-	-	-	-	-
		5:30 pm	-	-	14.5	0.4	-	-	-	-	-
	4/6	2:30 pm	-	-	13.0	0.6	-	-	-	-	-
	4/7	7:00 pm	-	46.0	13.0	0.3	-	-	-	-	-
ASP2 (out)	4/3	3:30 pm	-	1.0	-	-	-	-	-	-	3.1×10^6
	4/6	9:15 am	-	0.8	-	-	-	-	106	-	-
	4/5	3:00 pm	-	<0.1	-	-	-	-	-	-	-
		5:30 pm	-	-	15	6.8	-	-	-	-	-
	4/6	2:30 pm	-	-	13.5	7.0	-	-	-	-	-
	4/7	7:00 pm	-	33.0	13.0	2.5	-	-	-	-	-
AT comp. (in)	4/7	6:00 pm	-	34.0	-	-	-	-	-	-	-
		7:00 pm	-	-	-	-	116	70	-	-	-
	4/10	5:15 pm	-	15.0	-	-	89	40	-	-	-
	4/12	5:00 pm	-	29.1	-	-	-	-	-	-	-
	4/13	11:00 am	-	21.5	-	-	104	41	-	-	-
	4/14	9:00 am	-	25.0	-	-	98	45	-	-	-
		1:00 pm	-	33.0	-	-	108	58	-	-	-
AT comp. (out)	4/7	6:00 pm	-	16.6	-	-	-	-	-	-	-
		7:00 pm	-	-	-	-	61	34	-	-	-
	4/10	5:15 pm	-	0.6	-	-	44	38	-	-	-
	4/12	5:00 pm	-	0.4	-	-	-	-	-	-	-
	4/13	11:00 am	-	<0.1	-	-	68	36	-	-	-
	4/14	9:00 am	-	< .1	-	-	72	36	-	-	-
		1:00 pm	-	0.3	-	-	70	34	-	-	-
PSF1	4/3	3:30 pm	-	0.1	-	-	-	-	-	-	-
	4/6	9:15 am	-	<0.1	-	-	-	-	96	-	-
	4/5	3:00 pm	-	<0.1	-	-	-	-	-	-	-
	4/6	9:00 pm	-	<0.1	-	-	-	-	-	0.6	-
	4/12	5:00 pm	-	0.1	-	-	-	-	-	-	-
PSF2	4/3	3:30 pm	-	<0.1	-	-	-	-	-	-	-
	4/6	9:15 am	-	0.7	-	-	-	-	94	-	-
	4/5	3:00 pm	-	<0.1	-	-	-	-	-	-	-
	4/12	5:00 pm	-	0.1	-	-	-	-	-	-	-
PE (comp)	4/3	12:00 n	-	0.3	-	-	-	-	-	-	-
		6:00 pm	-	9.7	-	-	-	-	-	-	-
	4/10	11:00 am	-	0.1	-	-	-	-	-	-	-
		12:30 pm	-	<0.1	-	-	48	23	-	-	-
		5:15 pm	-	0.1	-	-	61	22	-	-	-
	4/11	5:00 pm	-	0.6	-	-	-	-	-	-	-
		6:00 pm	-	-	-	-	73	30	-	-	3.0×10^5
	4/14	9:00 am	-	<0.1	-	-	75	37	-	0.7	-
		1:00 pm	-	0.1	-	-	73	38	-	0.6	-
PE_{TP}	4/6	9:15 am	-	3.5	-	-	-	-	106	-	-
		3:00 pm	-	10.2	-	-	-	-	-	-	-
		5:00 pm	-	11.2	-	-	-	-	-	-	-
	4/5	4:40 pm	-	11.5	-	-	-	-	-	-	-
	4/10	5:15 pm	-	13.8	-	-	-	-	-	-	-
	4/13	10:00 am	-	10.0	-	-	105	59	-	-	-
	4/14	9:00 am	16	10.4	-	-	97	50	-	-	-
		1:00 pm	-	9.2	-	-	114	58	-	-	-
Int.Pl.Eff.	4/10	5:15 pm	-	11.2	-	-	-	-	-	-	-
	4/13	10:00 am	-	12.0	-	-	135	76	-	-	-
	4/14	9:00 am	-	11.8	-	-	97	48	-	-	-
		1:00 pm	-	11.0	-	-	104	51	-	-	-

and the accumulated sludge was returned through the system as a slug of highly concentrated solids and phosphate. Most of the concentrated sludge had moved through the aeration tanks when the samples were collected at 6:00 and 7:00 p.m. and was primarily affecting the final effluent and Aeration Tank No. 2 effluent, which had phosphate concentrations of 9.7 and 33 mg/l, respectively. The average mixed liquor detention of approximately five hours in the aeration tanks was not sufficient to remove this large concentration of soluble phosphate (See Jug Experiment No. 3).

Aeration Tank No. 2 was slower in recovering from the high phosphate loads because of the lower dissolved oxygen concentrations normally found in the front of this tank. Figure No. 5 presents typical soluble phosphate and dissolved oxygen concentrations versus location in the aeration tanks determined two days prior to the malfunction. The DO lag in Tank No. 2 was believed due to a particularly heavy slime growth on the diffusion plates in this tank. The effect is the delay in phosphate removal in Tank No. 2.

The differences in phosphate concentrations shown in Table No. 1 for the aeration tank influents (AT in) indicate typical variations for phosphate removing plants. Both tanks receive common primary effluent and return sludge and should have similar phosphate concentrations; however, insufficient mixing due to the primary effluent and the return sludge discharging into the tanks through individual pipes accounts for much of the difference. Delay in sample analysis would also contribute, since bleedback is time dependent. Characteristically, activated sludge plants that are removing phosphate show the influent mixed liquor orthophosphate concentration to be much higher than that due to combination of synthesis components. The higher concentration is the result of rapid desorption of orthophosphate from the return sludge solids upon contact with primary effluent containing little or no dissolved oxygen. Such was the case for aeration tank influent samples analyzed during this study.

Both final clarifiers maintain a dissolved oxygen concentration of about 3 mg/l in the tanks near the overflow weirs. (DO concentrations increase toward the center of the clarifiers.) These high DO's apparently prevent desorption of soluble phosphate from the sludge solids, and indications were that additional sorption may actually be occurring in the clarifiers. Sometimes, slime accumulations reduce these DO concentrations to about 1.0 mg/l. At such times, the clarifiers are emptied, cleaned, and restored to normal operation.

Sludge blanket depths were generally kept low in the final clarifiers. The sludge depth measured less than one foot deep at the outer edge but increased to as much as 5 feet near the center. This increase was due to the slope of the bottom of the clarifier plus a gentle rise in sludge levels toward the center.

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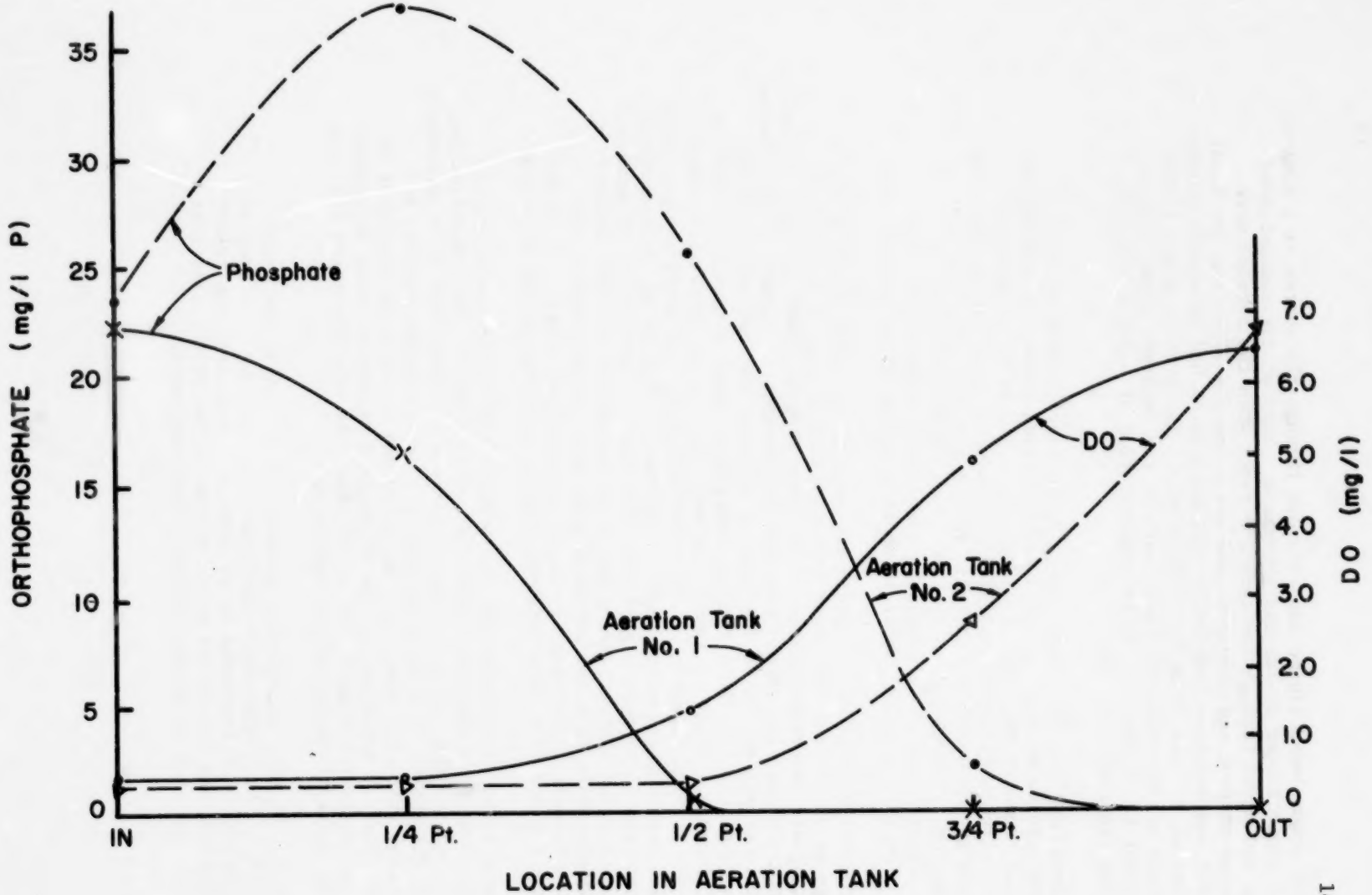

FIGURE 5 – PHOSPHATE REMOVAL IN AERATION TANKS

2. Trickling Filter System

The trickling filter plant was sampled on several occasions to determine phosphate removals. Samples were taken at the trickling filter influent (PE_{TF}), trickling filter effluent (FE_{TF}), and the humus tank effluent (Tot. Pl. Eff.); and the data are presented in Table No. 2. Soluble phosphate concentrations entering the trickling filter system were similar to those entering the activated sludge system; however, average effluent concentrations were greater than the influent concentrations to the trickling filter. It was concluded that the trickling filter system was not removing soluble phosphate.

Aeration Jug Studies

Aeration Tank and Jug Comparison: Three jugs of mixed liquor from the influent end of Aeration Tank No. 1 were aerated in parallel at 5, 10, and 15 liters per minute of air, respectively. During the jug aeration, two slugs of waste were followed through Tank No. 1 on the basis of a 5-hour detention time as determined by dye tracer studies. The tank was sampled at the influent, 1/8 point, 1/4 point, 1/2 point, 3/4 point, and effluent. All samples were analyzed for orthophosphate. Selected samples were analyzed for suspended solids, plate count, total phosphate, magnesium, calcium, and total and organic carbon for further comparison of tank and jug operation. Temperature and dissolved oxygen were monitored in the jugs and in the tanks. The data are presented in Table No. 3.

Figure No. 6 illustrates the similarity of phosphate removal in the aeration tanks and jugs. The rate of phosphate removal in the jugs increased with the rate of air supplied over the range studied. The rate at which Aeration Tank No. 1 removed phosphate falls between the aeration jugs supplied at 5 and 10 liters of air per minute. This does not mean that more than 5 liters of air per minute per 15 liters of sewage is comparable to that supplied to the aeration tanks. The air transfer system is much better in the aeration tank, due to diffusion plates and smaller bubbles, so that about 7 or 8 liters of air per minute per 15 liters of mixed liquor or about 0.5 liters/minute/liter must be applied in the jugs to obtain phosphate removal equivalent to that obtained in the aeration tanks at 0.02 liters of air/minute/liter.*

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*Since aeration to a batch system such as the jug cannot be converted to cubic feet of air per gallon of waste without assuming some detention time, the aeration to the plant was assumed to be an instantaneous batch system. Therefore, 14,000 ft^3/min or 40,000 liters per minute is the aeration rate and the volume of the theoretical batch system is the volume of the aeration tanks; i.e., 5.2×10^6 gallons or about 2×10^7 liters.

Table No. 3

JUG AND AERATION TANK COMPARISON - APRIL 6, 1967

Sample	Time	TSS (mg/l)	Ortho Phosphate (mg/l P)	Temp (°C)	DO (mg/l)	Carbon Total (mg/l)	Carbon Organic (mg/l)	Total Phosphate (mg/l P)	Ca* (mg/l)	Mg* (mg/l)	Total Plate Count (count/ml)
Jug #1	2:30 pm	1920	24.4	-	-	122	48	95.6	-	-	7.8×10^5
	3:00 pm	-	32.0	16.5	0.5	-	-	-	-	-	-
	3:30 pm	2310	33.0	-	-	122	42	89.4	46.5	30.0	-
	4:00 pm	-	-	-	-	-	-	-	-	-	-
	4:30 pm	-	22.8	18.0	0.2	78	31	91.2	57.5	40.0	6.5×10^5
	5:00 pm	-	20.4	-	-	-	-	-	-	-	-
	5:30 pm	1970	17.1	18.5	0.2	75	30	91.2	35.5	12.3	1.3×10^5
	6:00 pm	-	12.8	-	-	-	-	86.2	-	-	-
	6:30 pm	-	6.6	19.0	0.2	-	-	-	-	-	1.2×10^5
	7:30 pm	-	<0.1	19.0	2.0	73	-	78.2	74.5	44.5	2.0×10^5
	8:30 pm	-	<0.1	-	3.5	-	-	-	-	-	-
Jug #2	2:30 pm	-	25.4	-	-	-	-	-	-	-	-
	3:00 pm	-	18.8	17.5	1.4	-	-	-	-	-	-
	3:30 pm	-	7.9	-	-	-	-	-	-	-	-
	4:00 pm	-	2.6	-	-	-	-	-	-	-	-
	4:30 pm	-	0.6	19.0	5.0	-	-	-	-	-	-
	5:00 pm	-	<0.1	-	-	-	-	-	-	-	-
	5:30 pm	-	0.3	19.0	6.2	-	-	-	-	-	-
	6:00 pm	-	<0.1	-	-	-	-	-	-	-	-
	6:30 pm	-	<0.1	19.5	6.5	-	-	86.2	-	-	1.3×10^5
Jug #3	2:30 pm	-	24.4	-	-	84	42	-	-	-	-
	3:00 pm	-	14.0	16.0	4.5	-	-	-	-	-	-
	3:30 pm	-	6.6	-	-	-	-	-	-	-	-
	4:00 pm	-	2.0	-	-	-	-	-	-	-	-
	4:30 pm	-	0.2	17.0	7.0	-	-	-	-	-	-
	5:00 pm	-	<0.1	-	-	-	-	-	-	-	-
	5:30 pm	-	<0.1	18.0	6.7	-	-	-	-	-	-
	6:00 pm	-	<0.1	-	-	-	-	-	-	-	-
	6:30 pm	-	<0.1	18.0	7.0	-	-	83.8	-	-	1.5×10^5
AT #1 (in) [1]	2:00 pm	-	-	15.0	0.5	-	-	-	-	-	-
	2:30 pm	1580	18.6	-	-	86	50	90.0	-	-	1.6×10^6
	3:30 pm	2020	23.5	-	-	-	-	83.8	49.5	33.0	1.0×10^5
	4:30 pm	-	-	15.5	0.5	-	-	-	-	-	-
AT #1(1/8 pt)	3:10 pm	-	24.2	-	-	-	-	92.0	-	-	-
	4:10 pm	-	22.1	-	-	-	-	87.5	-	-	-
	4:50 pm	-	-	15.0	0.6	-	-	-	-	-	-
AT#1(1/4 pt)	2:00 pm	-	-	15.0	0.6	-	-	-	-	-	-
	3:45 pm	2080	17.4	-	-	73	32	96.2	-	-	1.1×10^6
	4:30 pm	-	-	15.0	0.7	-	-	-	-	-	-
	4:45 pm	-	15.1	-	-	80	37	86.2	-	-	-
AT #1(1/2 pt)	2:00 pm	-	-	15.0	3.2	-	-	-	-	-	-
	4:30 pm	-	-	15.0	4.0	-	-	-	-	-	-
	5:00 pm	2230	<0.1	-	-	75	29	87.5	53.0	34.0	2.6×10^5
	6:00 pm	-	<0.1	-	-	77	31	96.2	-	-	-
AT #1(3/4 pt)	2:00 pm	-	-	15.5	6.3	-	-	-	-	-	-
	4:30 pm	-	-	15.0	6.3	-	-	-	-	-	-
	6:15 pm	-	<0.1	-	-	-	-	92.5	-	-	-
	7:15 pm	-	<0.1	15.5**	6.2**	-	-	87.5	-	-	-
AT #1(out)	2:00 pm	-	-	15.5	7.2	-	-	-	-	-	-
	4:30 pm	-	-	15.5	7.3	-	-	-	-	-	-
	7:30 pm	2090	<0.1	15.5	7.8	67	43	85.0	46.5	33.6	2.5×10^5
	8:30 pm	-	<0.1	-	-	72	28	-	-	-	8.1×10^4
FE #1 [2]	9:00 pm	-	<0.1	-	-	-	-	0.8	-	-	-

*Total - organic plus inorganic

** 7:30 p.m. measurement

1/ AT - Aeration Tank
2/ Effluent from Final Clarifier No. 1

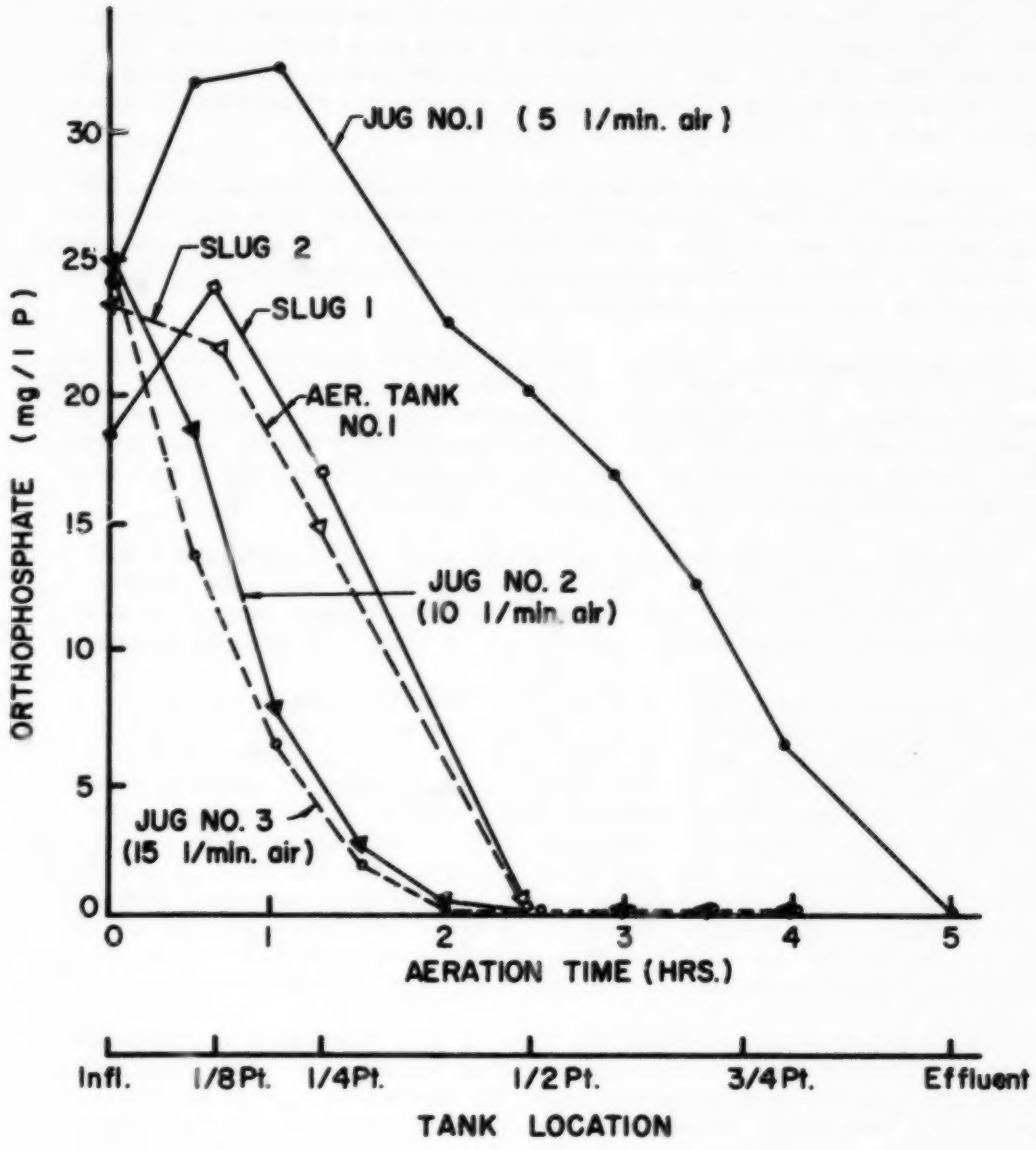

FIGURE 6 —AERATION TANK AND JUG COMPARISON

It is obvious that jugs could be aerated as low as 5 liters of air per minute and obtain as much overall phosphate removal as those aerated at higher rates. However, the initial bleedback or desorption is greater at the lower aeration rates and requires a greater detention time to accomplish the removal. The same is true in the aeration tanks as noted by the difference in dissolved oxygen and phosphate concentrations for Aeration Tanks No. 1 and 2 shown in Figure No. 5.

The above results show the similarity of aeration jug and aeration tank performance and add reliability to the prediction from jug tests of sewage and sludge amenability to phosphate removal. The soluble phosphate and DO data in Table No. 3 again establish the relationship of these two parameters in both aeration tank and jug.

Jug Experiments No. 1 and 2: Two sets of six aeration jugs were set up--one at 10:30 a.m. on April 4 and another at 12:15 a.m. on April 5, 1967. These experiments were designed to determine the effect of mixed-liquor suspended solids concentration on soluble phosphate removal. The inputs of air, return sludge, primary effluent, and mixed liquor are given in Table No. 4, and the results are listed in Table No. 5.

Suspended solids concentrations in the jugs ranged from about 800 to 6,000 mg/l. As shown in Figures Nos. 7 and 8, all the jugs, except the one containing 815 mg/l TSS, removed over 99 percent of the soluble phosphate within four hours of aeration at 15 liters of air per minute.

As noted in Figure No 7, the initial concentrations of soluble phosphate in the jugs generally increased with an increase in mixed liquor suspended solids (MLSS). This finding is in agreement with research conducted at San Antonio where the desorption of soluble phosphate was found to be dependent upon mixed liquor solids concentration. Jug No. 4 is an exception to this statement, but it was prepared in a different manner. The contents of this jug came directly from the head of one of the aeration tanks rather than being prepared by mixing primary effluent and return sludge. The contents of Jug No. 4 could have been present in the influent end of the aeration tank for several minutes before collection, permitting greater phosphate desorption time than in the other jugs.

Figure No. 8 shows that all the jugs in Jug Experiment No. 2 removed more than 95 percent of the probable initial soluble phosphate concentrations. The initial samples were accidently discarded before phosphate measurements were made. Experiment No. 2 was significant in that the soluble phosphate concentrations in all the jugs were reduced to less than 1.0 mg/l P in slightly more than two hours of aeration.

The final soluble phosphate concentrations of all jugs containing more than about 1,200 mg/l MLSS were almost identical. An optimum level

Table No. 4

Components of Aeration Jugs

Jug Experiment No. 1

Components	1	2	3	4	5	6	Ortho Phosphate (mg/1 P)	TSS (mg/1)
PE (1)[1]	10.0	10.0	10.0	-	10.0	10.0	7.8	52
RS (1)[2]	0.9	1.8	2.7	-	4.5	5.4	31.6	9930
FE (1)[3]	4.1	3.2	2.3	-	0.5	-	<0.1	-
ML (1)[4]	-	-	-	15.0[5]	-	-	32.0	2315
Air (1/min)	15	15	15	15	15	15	-	-

Jug Experiment No. 2

PE (1)	-	-	10	10	10	-	-	-
RS (1)	-	-	5	10[6]	15[6]	-	-	-
ML (1)	15[7]	15[8]	-	-	-	-	-	2598[7]
Air (1/min)	10	10	10	10	10	-	-	2210[8]

Jug Experiment No. 3

PE (1)	2.5	5.0	10.0	10.0	10.0	10.0	7.6	165
RS (1)	3.0	3.0	3.0	3.0	3.0	3.0	535	-
FE (1)	9.5	7.0	2.0	2.0	2.0	2.0	0.3	-
Met.[9] (ml)	-	-	-	2.5	5.0	10.0	-	-
Air (l/min)	15	15	15	15	15	15	-	-

[1] PE - Primary Effluent
[2] RS - Return Sludge
[3] FE - Final Effluent
[4] ML - Mixed Liquor
[5] Mixed Liquor From Influent of Aeration Tank No. 2
[6] Concentrated by Sludge Flotation to 5 Liters
[7] Mixed Liquor From Influent of Aeration Tank No. 1
[8] Mixed Liquor From Influent of Aeration Tank No. 2
[9] BOD of Metrecal is 290 mg/ml

Table No. 4
(Continued)

Components of Aeration Jugs

Components	1	2	3	4	5	6	Ortho Phosphate (mg/l P)	TSS (mg/l)
Jug Experiment No. 4								
PE (l)	2.5	5.0	10.0	10.0	10.0	10.0	9.0	207
RS (l)	3.0	3.0	3.0	3.0	3.0	3.0	13.0	8870
FE (l)	9.5	7.0	2.0	2.0	2.0	2.0	0.03	-
Met. (ml)	-	-	-	2.5	5.0	10.0	-	-
Air (l/min)	15	15	15	15	15	15	-	-
Jug Experiment No. 5								
PE (l)	6	6	6	6	6	-	8.9	-
RS (l)	3	3	3	3	3	-	8.5	-
DW[1/] (l)	6	6	6	6	6	-	-	-
ML[2/] (l)	-	-	-	-	-	15	21.5	2550
Met. (ml)	2.5	2.5	2.5	2.5	2.5	-	-	-
$MgSO_4$ (mg/l)	4	-	-	4	-	-	-	-
$FeCl_3$ (mg/l)	-	25	-	25	-	-	-	-
$Al_2(SO_4)_3$ (mg/l)	-	-	25	25	-	-	-	-
Jug Experiment No. 6								
PE (l)	10	10	10	10	10	10	12.0	-
RS (l)	3	5	10[3/]	20[3/]	10[4/]	10[4/]	37.5	-
FE (l)	2	-	-	-	-	-	0.1	-
K_2HPO_4 (mg/l)	-	-	-	-	-	75	-	-

[1/] Distilled Water
[2/] Composite of Aeration Tank Influents
[3/] Concentrated by Sludge Flotation to 5 Liters
[4/] Acidified, Washed Twice, and Concentrated to 5 Liters

Table No. 5

EXPERIMENTAL RESULTS - JUG EXPERIMENTS 1, 2, & 3

Jug Experiment No. 1 - Low Solids - April [illegible], 1967

Sample	Time	TSS (mg/l)	Ortho Phosphate (mg/l P)	Temp °C	DO (mg/l)	Carbon Total (mg/l)	Carbon Organic (mg/l)
Jug #1	10:30 am	770	7.0	14.5	3.5	-	-
	11:00 am	-	5.0	-	-	-	-
	11:30 am	-	4.6	14.0	7.6	-	-
	12:30 pm	-	2.6	-	-	-	-
	12:45 pm	-	-	13.0	8.7	-	-
	1:30 pm	-	2.2	13.0	8.7	-	-
	2:30 pm	-	2.6	-	-	410	430
	3:30 pm	860	2.0	-	-	-	-
	3:45 pm	-	-	18.0	8.2	-	-
	4:30 pm	-	5.0	-	-	-	-
Jug #2	10:30 am	1260	11.0	15.5	2.5	-	-
	11:00 am	-	5.0	-	-	-	-
	11:30 am	-	2.7	14.5	8.0	-	-
	12:30 pm	-	1.3	-	-	-	-
	12:45 pm	-	-	13.5	8.8	-	-
	1:30 pm	-	0.1	13.0	8.7	-	-
	2:30 pm	-	0.3	-	-	570	610
	3:30 pm	1216	0.2	-	-	-	-
	3:45 pm	-	-	17.0	8.5	-	-
Jug #3	10:30 am	1830	13.0	14.5	1.8	-	-
	11:00 am	-	4.0	-	-	-	-
	11:30 am	-	2.2	14.0	6.2	-	-
	12:30 pm	-	<0.1	-	-	-	-
	12:45 pm	-	-	13.0	8.0	-	-
	1:30 pm	-	<0.1	13.0	8.0	-	-
	2:30 pm	-	0.1	-	-	900	700
	3:30 pm	1784	0.1	-	-	-	-
	3:45 pm	-	-	14.0	9.5	-	-
Jug #4	10:30 am	1990	32.0	14.5	1.8	-	-
	11:00 am	-	21.0	-	-	-	-
	11:30 am	-	10.4	14.0	5.7	-	-
	12:30 pm	-	3.6	-	-	-	-
	12:45 pm	-	-	13.0	7.5	-	-
	1:30 pm	-	1.1	12.0	7.5	-	-
	2:30 pm	-	0.1	-	-	1300	1040
	3:30 pm	2440	0.3	-	-	-	-
	3:45 pm	-	-	14.0	8.3	-	-
Jug #5	10:30 am	2950	18.0	15.0	1.4	-	-
	11:00 am	-	8.0	-	-	-	-
	11:30 am	-	0.6	15.0	6.7	-	-
	12:30 pm	-	<0.1	-	-	-	-
	12:45 pm	-	-	14.0	8.0	-	-
	1:30 pm	-	<0.1	13.0	8.8	-	-
	2:30 pm	-	0.2	-	-	1120	1160
	3:30 pm	3010	0.1	-	-	-	-
	3:45 pm	-	-	14.0	8.6	-	-
Jug #6	10:30 am	3660	22.0	17.0	0.5	-	-
	11:00 am	-	17.0	-	-	-	-
	11:30 am	-	2.6	18.0	2.2	-	-
	12:30 pm	-	<0.1	-	-	-	-
	12:45 pm	-	-	16.0	7.0	-	-
	1:30 pm	-	<0.1	15.0	6.0	-	-
	2:30 pm	-	0.1	-	-	1520	1380
	3:30 pm	3890	0.4	-	-	-	-
	3:45 pm	-	-	13.5	9.0	-	-

Jug Experiment No. 2 - High Solids - April 5, 1967

Sample	Time	TSS (mg/l)	Ortho Phosphate (mg/l P)	Temp °C	DO (mg/l)
Jug #1	12:15 pm	2600	*	-	-
	12:30 pm	-	-	14.5	0.3
	12:45 pm	-	24.5	-	-
	1:00 pm	-	15.4	-	-
	1:30 pm	-	9.5	-	-
	2:00 pm	-	4.0	14.0	3.2
	2:30 pm	-	0.4	-	-
	3:15 pm	-	0.1	-	-
	3:45 pm	-	-	15.5	5.6
	4:30 pm	2595	<0.1	-	-
Jug #2	12:15 pm	2370	*	-	-
	12:30 pm	-	-	13.5	0.3
	12:45 pm	-	25.0	-	-
	1:00 pm	-	17.4	-	-
	1:30 pm	-	9.4	-	-
	2:00 pm	-	3.8	15.0	3.7
	2:30 pm	-	0.4	-	-
	3:15 pm	-	0.1	-	-
	3:45 pm	-	-	16.0	5.8
	4:30 pm	2050	0.2	-	-
Jug #3	12:15 pm	3530	*	-	-
	12:30 pm	-	-	14.5	0.3
	12:45 pm	-	19.5	-	-
	1:00 pm	-	30.2	-	-
	1:30 pm	-	8.4	-	-
	2:00 pm	-	1.4	14.5	0.3
	2:30 pm	-	0.2	-	-
	3:15 pm	-	0.1	-	-
	3:45 pm	-	-	16.0	4.4
	4:30 pm	3360	<0.1	-	-
Jug #4	12:15 pm	3990	*	-	-
	12:30 pm	-	-	13.0	0.2
	12:45 pm	-	16.0	-	-
	1:00 pm	-	16.6	-	-
	1:30 pm	-	8.2	-	-
	2:00 pm	-	1.2	13.0	0.2
	2:30 pm	-	0.2	-	-
	3:15 pm	-	<0.1	-	-
	3:45 pm	-	-	14.0	3.2
	4:30 pm	3690	0.2	-	-
Jug #5	12:15 pm	5830	*	-	-
	12:30 pm	-	-	13.0	0.5
	12:45 pm	-	19.0	-	-
	1:00 pm	-	14.1	-	-
	1:30 pm	-	7.6	-	-
	2:00 pm	-	1.2	13.0	0.2
	2:30 pm	-	0.3	-	-
	3:15 pm	-	0.1	-	-
	3:45 pm	-	-	13.5	0.9
	4:30 pm	8340	0.6	-	-

*Samples lost

Jug Experiment No. 3 - BOD Addition - April 7, 1967

Sample	Time	TSS (mg/l)	Ortho Phosphate (mg/l P)	Temp °C	DO (mg/l)	Carbon Total (mg/l)	Carbon Organic (mg/l)
Jug #1	12:00 N	5360	120	14.5	0.2	162	146
	12:30 pm	-	-	14.0	0.2	-	-
	1:00 pm	-	108	14.0	0.2	117	87
	1:30 pm	-	92	13.0	0.7	-	-
	2:00 pm	-	78	13.0	1.5	-	-
	2:30 pm	-	-	13.0	2.5	-	-
	3:00 pm	-	62	15.0	2.5	-	-
	4:00 pm	-	36	-	-	-	-
	5:00 pm	5290	11	23.0	3.0	-	-
	6:00 pm	-	3.0	-	-	114	64
	6:30 pm	-	-	20.0	3.7	-	-
	7:00 pm	-	0.6	-	-	-	-
	7:30 pm	-	-	17.0	4.5	-	-
Jug #2	12:00 N	5000	116	15.0	0.3	148	141
	12:30 pm	-	-	15.0	0.3	-	-
	1:00 pm	-	116	14.5	0.3	110	82
	1:30 pm	-	86	14.0	1.6	-	-
	2:00 pm	-	76	14.0	2.6	-	-
	2:30 pm	-	-	14.0	3.3	-	-
	3:00 pm	-	56	15.0	3.5	-	-
	4:00 pm	-	36	-	-	-	-
	5:00 pm	5180	16	21.5	3.5	-	-
	6:00 pm	-	3.0	-	-	116	66
	6:30 pm	-	-	20.0	5.0	-	-
	7:00 pm	-	0.6	-	-	-	-
	7:30 pm	-	-	17.5	5.6	-	-
Jug #3	12:00 N	5150	122	14.0	0.2	201	141
	12:30 pm	-	-	13.5	0.2	-	-
	1:00 pm	-	128	13.5	0.2	120	86
	1:30 pm	-	108	13.0	0.3	-	-
	2:00 pm	-	94	13.0	1.2	-	-
	2:30 pm	-	-	13.0	1.8	-	-
	3:00 pm	-	76	14.0	1.8	-	-
	4:00 pm	-	44	-	-	-	-
	5:00 pm	-	20	20.0	2.6	-	-
	6:00 pm	-	3.6	-	-	114	68
	6:30 pm	-	-	18.0	4.0	-	-
	7:00 pm	-	0.6	-	-	-	-
	7:30 pm	-	-	16.0	4.6	-	-
Jug #4	12:00 N	4310	122	14.0	0.2	189	171
	12:30 pm	-	-	13.0	0.2	-	-
	1:00 pm	-	126	13.0	0.2	126	92
	1:30 pm	-	98	12.5	0.4	-	-
	2:00 pm	-	90	12.5	1.3	-	-
	2:30 pm	-	-	12.5	2.0	-	-
	3:00 pm	-	68	13.5	2.0	-	-
	4:00 pm	-	44	-	-	-	-
	5:00 pm	4880	25	20	2.3	-	-
	6:00 pm	-	3.6	-	-	116	64
	6:30 pm	-	-	18	3.0	-	-
	7:00 pm	-	3.5	-	-	-	-
	7:30 pm	-	-	15.5	4.8	-	-
Jug #5	12:00 N	5130	130	14.0	0.2	193	159
	12:30 pm	-	-	13.0	0.2	-	-
	1:00 pm	-	146	13.0	0.2	150	116
	1:30 pm	-	130	12.5	0.2	-	-
	2:00 pm	-	106	12.5	0.3	-	-
	2:30 pm	-	-	12.5	0.8	-	-
	3:00 pm	-	76	13.5	1.0	-	-
	4:00 pm	-	36	-	-	-	-
	5:00 pm	5290	31	19.0	1.9	-	-
	6:00 pm	-	10.4	-	-	118	70
	6:30 pm	-	-	17.0	5.0	-	-
	7:00 pm	-	0.7	-	-	-	-
	7:30 pm	-	-	15.0	6.0	-	-
Jug #6	12:00 N	5230	122	14.0	0.5	216	192
	12:30 pm	-	-	13.0	0.5	-	-
	1:00 pm	-	146	13.0	0.5	156	128
	1:30 pm	-	130	12.5	0.5	-	-
	2:00 pm	-	116	12.5	0.5	-	-
	2:30 pm	-	-	12.5	0.5	-	-
	3:00 pm	-	88	13.5	0.5	-	-
	4:00 pm	-	68	-	-	-	-
	5:00 pm	5140	44	21.0	2.3	-	-
	6:00 pm	-	17.8	-	-	106	80
	6:30 pm	-	-	17.0	3.7	-	-
	7:00 pm	-	1.1	-	-	-	-
	7:30 pm	-	-	14.5	5.4	-	-

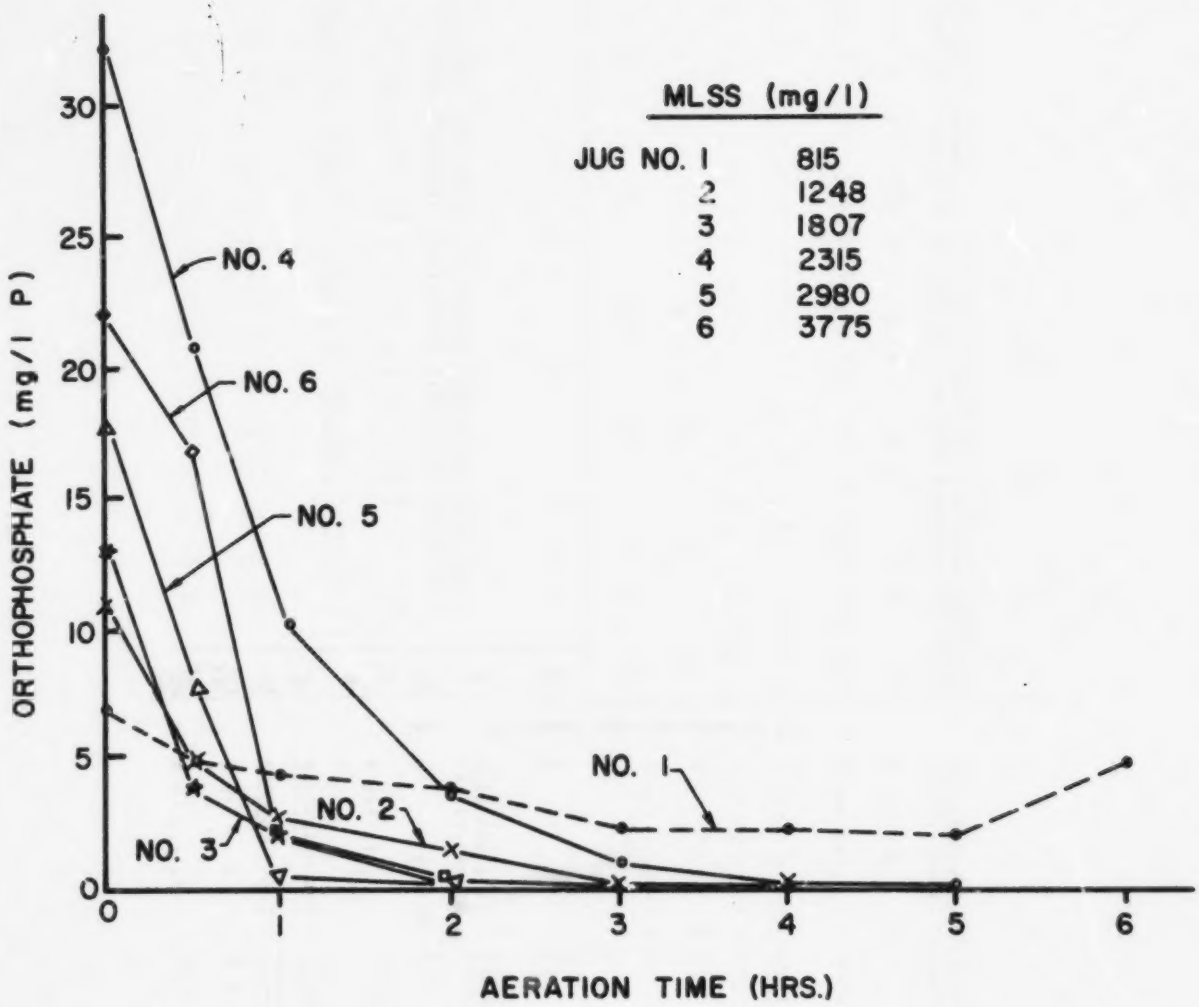

FIGURE 7 — EFFECT OF MLSS ON PHOSPHATE REMOVAL

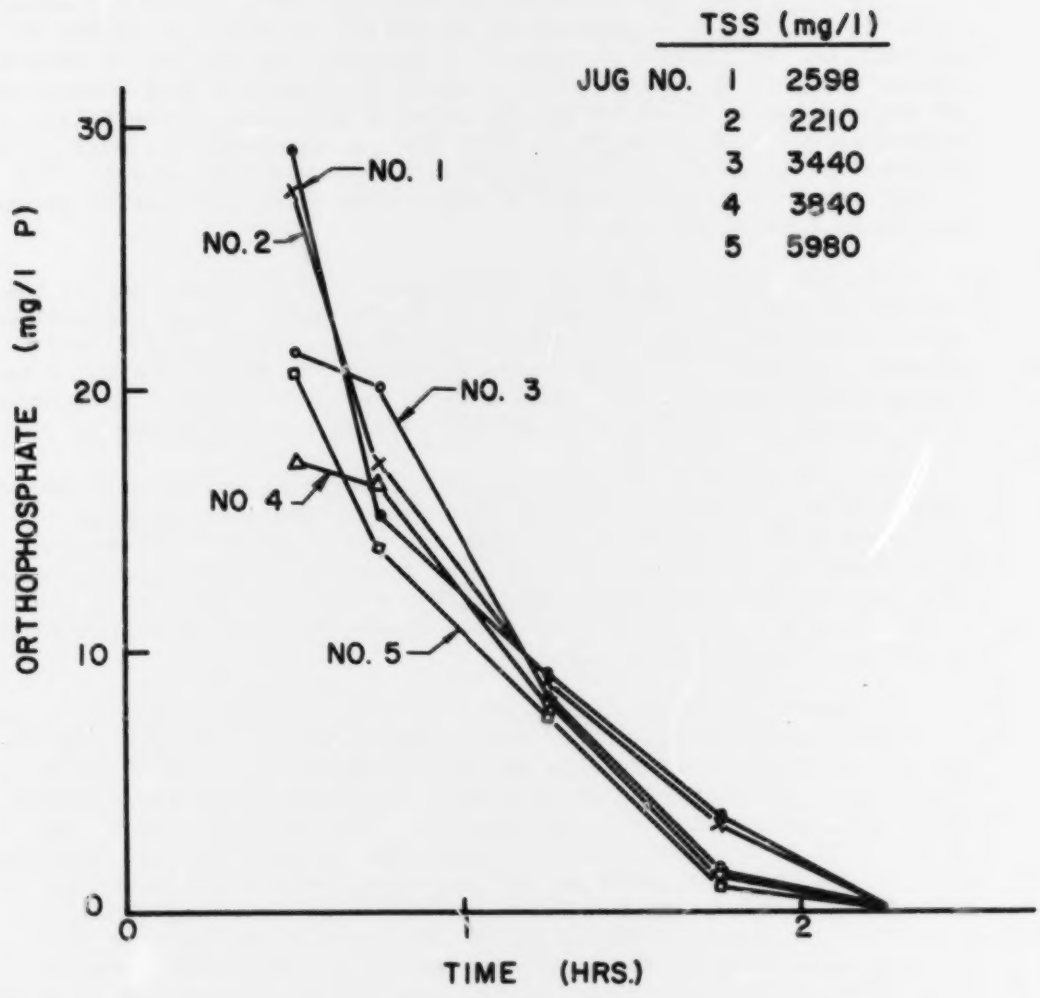

FIGURE NO. 8 — JUG EXPERIMENT NO. 2 : PHOSPHATE

of MLSS based on phosphate removal was not identified. Mixed liquor suspended solids for subsequent jug experiments were maintained at concentrations of 2,000-2,500 mg/l which were common to high phosphate removals in the plant.

Jug Experiment No. 3: A set of six jugs was prepared for aeration on April 7, 1967, to determine the effect of the addition of BOD as Metrecal on the removal of soluble phosphate. The mixture of return sludge and primary effluent was intended to produce a MLSS concentration of about 2,000 mg/l and an initial soluble phosphate concentration of approximately 25 mg/l as P; however, the return sludge was part of the abnormally concentrated slug mentioned earlier in this report. The result was MLSS concentrations of about 5,000 mg/l and initial phosphate concentrations of 120 mg/l P.

The BOD of the jug mixtures was assumed to be equivalent to the average of the primary effluent or about 200 mg/l. Final effluent was added to Jug No. 1 and 2 to dilute the BOD to an estimated 25 and 50 percent, respectively, of the normal waste. The BOD in Jug No. 3 was not altered. Metrecal was added to Jugs Nos. 4, 5, and 6 to produce an estimated BOD of 150, 200, and 300 percent, respectively.

Figure No. 9 presents the results of seven hours' aeration at 15 liters of air per minute. Soluble phosphate desorption generally increased with an increase in BOD during the first hour of aeration. After that time sorption started. The increased desorption indicates that the sorption-desorption equilibria is BOD dependent and substantiates results from the San Antonio studies which showed that desorption increases with increased BOD.

Following the initial desorption period, sorption began at a rate of approximately 16 mg/l P per hour. The result was greater than 95 percent of the initial soluble phosphate removed in 7 hours' aeration. This long aeration period at very high air rates necessary to remove such high concentrations of phosphate explain the inability of the aeration tanks to handle the phosphate load on April 7. The detention time in the aeration tanks and the air input were insufficient to remove the high initial phosphate concentration resulting from the long desorption period during the final clarifier malfunction. It was concluded that in the phosphate removal process, the detention time necessary for completion of the reaction is proportional to both the phosphate and BOD loads upon the system.

The major observation from this experiment is that the activated sludge at Baltimore is capable, with sufficient aeration and detention time, of removing phosphate concentrations greater than 10 times that normally found in raw wastes and greater than three times the mixed liquor phosphate concentrations normally found in the head end of Baltimore aeration tanks.

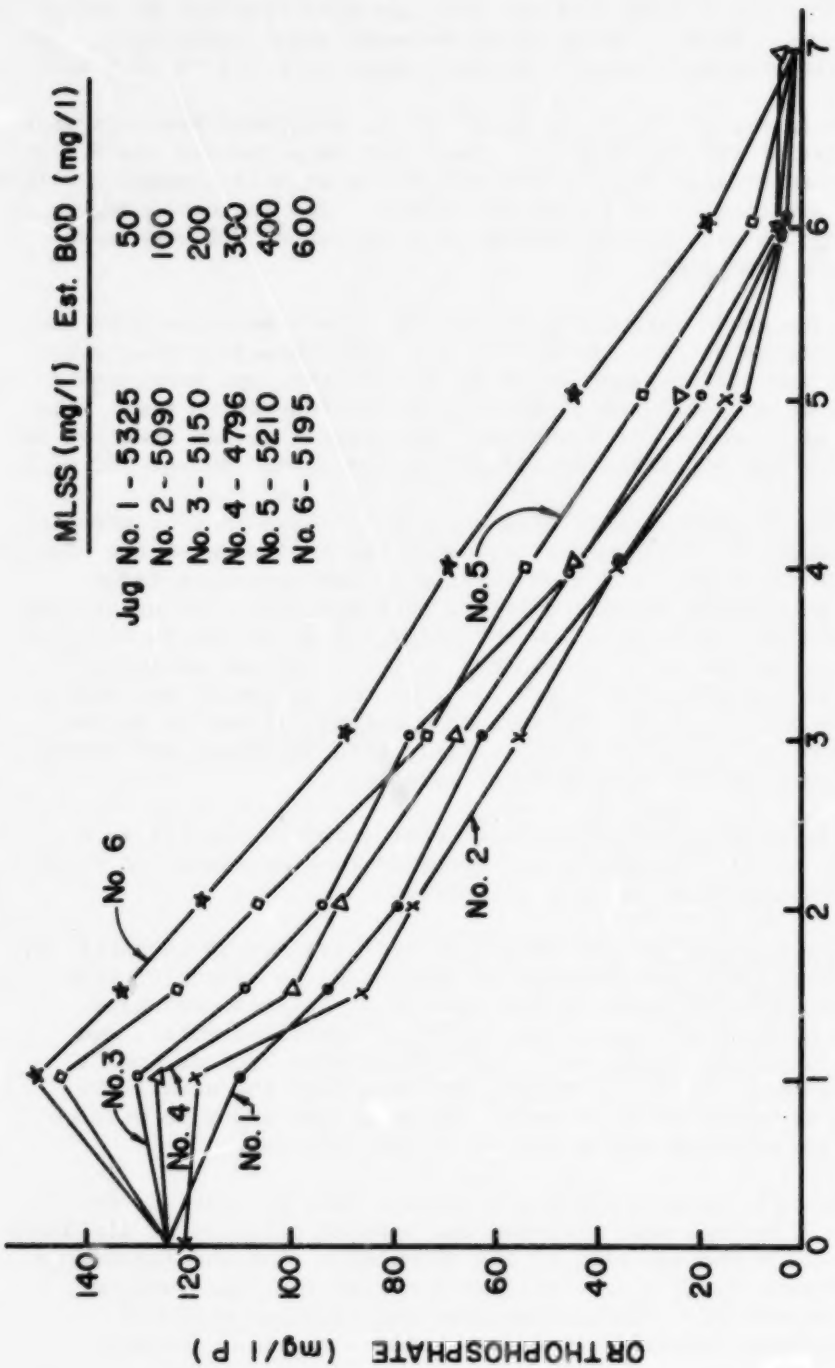

FIGURE 9 — EFFECT OF BOD ON PHOSPHATE REMOVAL

Jug Experiment No. 4: This was a repeat of Experiment No. 3 under normal operation conditions, and the six jugs were prepared in the identical manner. MLSS concentrations averaged about 1,800 mg/1, and initial soluble phosphate concentrations ranged from 7.4 to 18.8 mg/1 P.

As shown in Figure No. 10 and Table No. 6, phosphate removals were similar to that of the previous experiment but on a reduced scale. All the jugs removed greater than 95 percent of the soluble phosphate within two hours of aeration at 15 liters per minute. The increased degree of aerobic desorption and rate of removal with increased BOD were more evident in this experiment.

Total and organic carbon concentrations versus aeration time are presented in Figure No. 11. Except for the jug containing the lowest estimated BOD load (25 percent or 50 mg/1), all the jugs exhibited a general decrease in total and organic carbon with aeration time. The maximum rate of decrease for both total and organic carbon occurred in Jug No. 4 which had an estimated 150 percent of normal BOD or 300 mg/1.

Desorption of phosphate is shown by the increase in concentration of soluble phosphate in the mixed liquor at the beginning of the experiment over the value computed from the sum of the phosphate laden components. Desorption increased with additional BOD to an upper limit of 22 mg/1 P. The increase at low BOD values could be due to either the reduced concentration of components in the PE or the additional component of FE used in these jugs. In that the source of desorbable phosphate, the return sludge content, is constant, it may be assumed that desorption increases to an upper limit with increased BOD during the mixing period before initiation of aeration.

The increased desorption observed under aeration results in a retarding effect which increases the aeration time necessary to reach minimum concentrations of soluble phosphate.

Jug Experiment No. 5: Six aeration jugs were set up on April 13, 1967. This experiment was designed to determine the effect of iron, aluminum, and magnesium salts on the removal of soluble phosphate. Six liters of primary effluent, six liters of distilled water, and three liters of return sludge were combined to make up Jugs Nos. 1 through 5 to reduce the total calcium hardness from the normal 100 mg/1 as $CaCO_3$ to about 50 or 60 mg/1. Metrecal was added to make up the BOD lost by reducing the amount of primary effluent.

Figure No. 12 presents soluble phosphate versus aeration time for the six jugs. The jugs were prepared and aerated slightly at 11:15 a.m. and sampled before the addition of the chemicals. The chemicals were then added between 11:15 a.m. and 11:30 a.m. and the jugs sampled immediately thereafter. Addition of iron and aluminum produced immediate phosphate removal. Aluminum produced the most dramatic

JUG NO.	TSS (mg/l)	EST. BOD (mg/l)
1	1790	50
2	1690	100
3	1980	200
4	1740	300
5	1970	400
6	1990	600

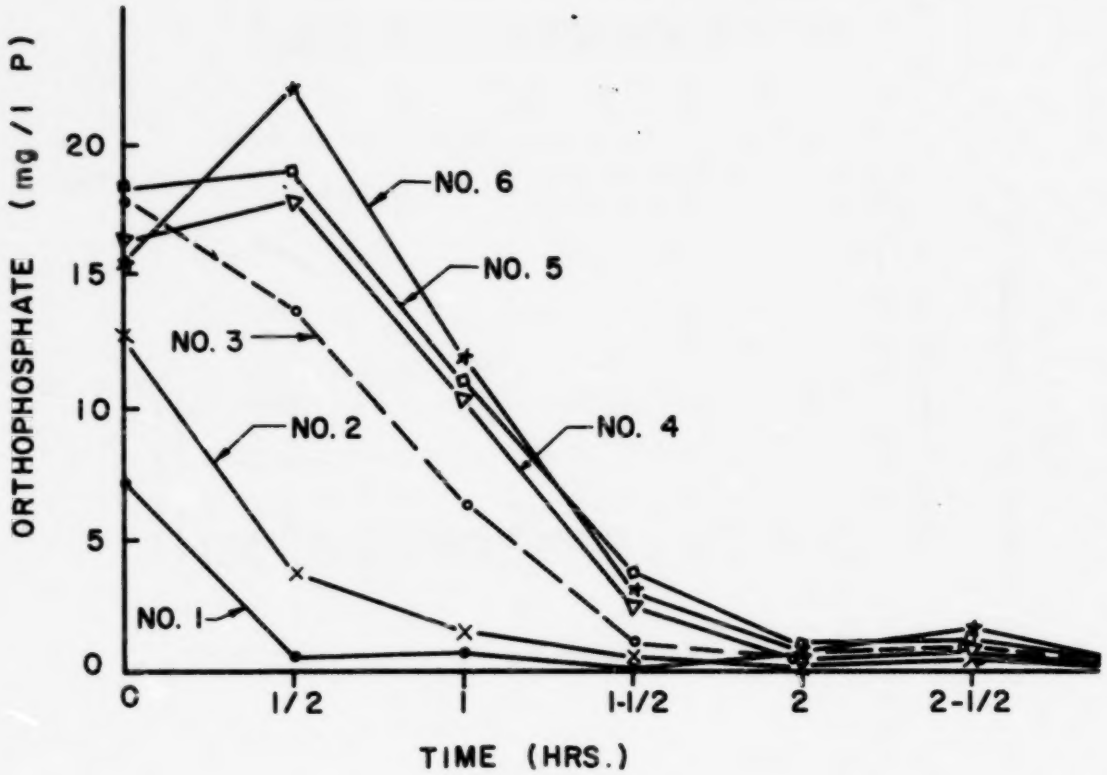

FIGURE NO.10— JUG EXPERIMENT NO. 4 : PHOSPHATE

Table No. 6

EXPERIMENTAL RESULTS - JUG EXPERIMENTS 4,5,& 6

Jug Experiment No. 4 - BOD Addition (Repeat) - April 10, 1967

Sample	Time	TSS (mg/l)	Ortho Phosphate (mg/l as P)	Temp °C	DO (mg/l)	Carbon Total (mg/l)	Carbon Organic (mg/l)	TDS (mg/l as Cl)	Total Plate Count (count/ml)
Jug #1	12:40 pm	1790	7.4	17.5	1.0	65	27	75	6.8×10^5
	1:10 pm	-	8.6	19.0	7.0	-	-	-	-
	1:40 pm	-	0.8	20.0	6.5	64	25	100	6.4×10^5
	2:10 pm	-	0.3	20.5	8.6	-	-	-	-
	2:40 pm	-	0.7	21.0	8.6	69	30	100	6.6×10^5
	3:10 pm	-	0.5	-	-	-	-	-	-
	3:40 pm	-	0.6	22.0	8.6	-	-	-	4.1×10^5
Jug #2	12:40 pm	1660	13.0	16.0	0.0	67	28	100	-
	1:10 pm	-	3.8	19.5	3.5	-	-	-	-
	1:40 pm	-	1.4	20.5	6.0	66	27	100	-
	2:10 pm	-	0.5	21.5	6.6	-	-	-	-
	2:40 pm	-	0.1	22.0	6.0	66	25	90	-
	3:10 pm	-	0.6	-	-	-	-	-	-
	3:40 pm	-	0.2	23.0	5.2	-	-	-	-
Jug #3	12:40 pm	1680	18.2	17.0	0.0	80	40	130	-
	1:10 pm	-	16.0	18.0	6.0	-	-	-	-
	1:40 pm	-	6.6	19.0	5.5	69	30	90	-
	2:10 pm	-	1.2	20.0	6.1	-	-	-	-
	2:40 pm	-	0.6	20.0	6.3	67	29	85	-
	3:10 pm	-	0.8	-	-	-	-	-	-
	3:40 pm	-	0.1	21.0	7.0	-	-	-	-
Jug #4	12:40 pm	1760	16.6	17.0	0.3	90	47	140	-
	1:10 pm	-	18.3	18.0	3.7	-	-	-	-
	1:40 pm	-	10.6	19.0	4.3	69	31	110	-
	2:10 pm	-	2.6	20.0	5.2	-	-	-	-
	2:40 pm	-	0.6	20.0	5.7	69	28	95	-
	3:10 pm	-	0.7	-	-	-	-	-	-
	3:40 pm	-	0.2	21.0	7.2	-	-	-	-
Jug #5	12:40 pm	1870	18.8	17.0	0.2	91	38	180	-
	1:10 pm	-	19.6	18.0	3.3	-	-	-	-
	1:40 pm	-	11.2	19.0	3.7	77	30	110	-
	2:10 pm	-	3.8	20.0	4.5	-	-	-	-
	2:40 pm	-	0.7	20.0	5.3	71	32	100	-
	3:10 pm	-	1.2	-	-	-	-	-	-
	3:40 pm	-	0.1	21.0	6.6	-	-	-	-
Jug #6	12:40 pm	1990	16.0	17.0	1.0	96	41	195	4.1×10^5
	1:10 pm	-	22.6	19.0	-	-	-	-	-
	1:40 pm	-	12.2	20.0	3.5	89	50	105	3.6×10^5
	2:10 pm	-	3.0	20.0	3.7	-	-	-	-
	2:40 pm	-	0.6	21.0	6.5	79	40	110	9.2×10^5
	3:10 pm	-	1.6	-	-	-	-	-	-
	3:40 pm	-	.0.1	22.0	5.7	-	-	-	6.9×10^5

Jug Experiment No. 5 - Metals Addition - April 13, 1967

Sample	Time	TSS (mg/l)	Ortho Phosphate (mg/l as P)	Temp °C	DO (mg/l)	Carbon Total (mg/l)	Carbon Organic (mg/l)	Total Hardness (CaCO$_3$) (mg/l)	Total Plate Count (count/ml)
Jug #1	11:15 am 1/	-	13.9	17.0	0.5	-	-	-	6.2×10^5
	11:30 am 2/	2650	17.9	16.0	2.5	54	56	-	6.8×10^5
	11:45 am	-	-	15.5	4.2	-	-	-	-
	12:00 n	-	9.0	15.0	5.6	-	-	-	-
	12:30 pm	-	6.8	14.5	6.2	-	-	-	3.9×10^5
	1:00 pm	2580	1.2	14.0	8.9	-	-	-	-
	1:30 pm	-	0.2	-	-	-	-	78.8	2.0×10^5
	2:00 pm	-	<0.03	-	-	-	-	-	-
	2:30 pm	-	0.2	-	-	-	-	-	3.7×10^5
	3:00 pm	-	0.7	-	-	54	56	-	-
Jug #2	11:15 am 1/	-	16.9	18.0	1.3	-	-	-	6.2×10^5
	11:30 am 2/	2380	18.0	17.0	1.3	57	62	-	5.8×10^5
	11:45 am	-	-	16.5	3.2	-	-	-	-
	12:00 n	-	9.8	15.5	5.6	-	-	-	-
	12:30 pm	-	8.2	15.0	6.2	-	-	-	2.9×10^5
	1:00 pm	2660	0.1	14.0	8.9	60	34	-	-
	1:30 pm	-	0.2	-	-	-	-	71.2	1.0×10^5
	2:00 pm	-	0.07	-	-	-	-	-	-
	2:30 pm	-	0.08	-	-	-	-	-	5.7×10^5
	3:00 pm	-	0.1	-	-	37	37	-	-
Jug #3	11:15 am 1/	-	16.4	18.0	0.0	-	-	-	2.1×10^5
	11:30 am 2/	1280	2.0	17.0	1.0	44	-	-	4.1×10^5
	11:45 am	-	-	15.0	5.7	-	-	-	-
	12:00 n	-	0.5	14.5	6.5	-	-	-	-
	12:30 pm	-	0.07	13.5	7.0	-	-	-	3.6×10^5
	1:00 pm	1770	0.07	13.0	7.0	38	37	-	-
	1:30 pm	-	0.03	-	-	-	-	101.0	2.0×10^5
	2:00 pm	-	<0.03	-	-	-	-	-	-
	2:30 pm	-	0.07	-	-	-	-	-	3.9×10^5
	3:00 pm	-	0.03	-	-	36	33	-	-
Jug #4	11:15 am 1/	-	16.5	15.0	0.2	-	-	-	-
	11:30 am 2/	1930	4.5	14.0	2.8	62	66	-	-
	11:45 am	-	-	13.5	7.6	-	-	-	-
	12:00 n	-	0.6	13.0	8.3	-	-	-	-
	12:30 pm	-	0.4	12.5	8.8	-	-	-	-
	1:00 pm	-	0.6	12.0	8.6	51	51	-	-
	1:30 pm	-	0.4	-	-	-	-	138.6	-
	2:00 pm	-	0.4	-	-	-	-	-	-
	2:30 pm	-	0.1	-	-	-	-	-	-
	3:00 pm	-	0.1	-	-	47	47	-	-
Jug #5	11:15 am 1/	-	13.0	14.0	1.2	-	-	-	5.5×10^5
	11:30 am 2/	1920	15.6	14.0	0.2	71	67	-	6.6×10^5
	11:45 am	-	-	13.5	3.7	-	-	-	-
	12:00 n	-	8.5	13.0	7.0	-	-	-	-
	12:30 pm	-	4.9	13.5	3.7	-	-	-	2.1×10^5
	1:00 pm	2370	3.6	13.0	10.5	62	36	-	-
	1:30 pm	-	2.0	-	-	-	-	66.0	4.0×10^5
	2:00 pm	-	0.2	-	-	-	-	-	-
	2:30 pm	-	0.2	-	-	-	-	-	3.0×10^5
	3:00 pm	-	0.07	-	-	35	33	-	-
Jug #6	11:15 am 1/	-	29.8	15.5	0.3	-	-	-	-
	11:30 am 2/	2550	29.4	15.0	1.2	85	68	-	-
	11:45 am	-	-	14.5	3.3	-	-	-	-
	12:00 n	-	17.5	14.0	4.5	-	-	-	-
	12:30 pm	-	11.0	13.0	6.2	-	-	-	-
	1:00 pm	-	4.8	13.0	8.5	78	61	-	-
	1:30 pm	-	4.0	-	-	-	-	101.2	-
	2:00 pm	-	1.1	-	-	-	-	-	-
	2:30 pm	-	0.9	-	-	-	-	-	-
	3:00 pm	-	0.3	-	-	76	38	-	-

1/Before addition of metals to Jugs 1-6.

2/After addition of metal to Jugs 1-6.

Jug Experiment No. 6 - Solids and PO_4 Variation - April 14, 1967

Sample	Time	TSS (mg/l)	Ortho Phosphate (mg/l as P)	Temp °C	DO (mg/l)	Carbon Total (mg/l)	Carbon Organic (mg/l)	Total Plate Count (count/ml)
Jug #1	2:30 pm	1220	16.0	17.5	7	97	71	-
	3:00 pm	-	4.0	18.0	1.1	-	-	-
	3:30 pm	-	0.2	21.0	3.7	-	-	-
	4:00 pm	-	0.1	23.0	3.8	79	30	-
	4:15 pm	-	-	25.0	3.8	-	-	-
	4:30 pm	-	0.1	25.3	4.3	-	-	-
	5:00 pm	1980	-	27.0	5.3	70	34	3.0×10^5
Jug #2	2:30 pm	4510	36.0	18.5	-	99	65	-
	3:00 pm	-	11.2	20.0	2.1	-	-	-
	3:30 pm	-	0.2	22.0	2.5	-	-	-
	4:00 pm	-	0.1	23.0	7.1	78	37	-
	4:15 pm	-	-	23.5	4.3	-	-	-
	4:30 pm	-	0.1	23.5	4.4	-	-	-
	5:00 pm	2920	-	-	-	67	36	3.3×10^5
Jug #3	2:30 pm	3370	21.5	17.0	0.2	95	63	-
	3:00 pm	-	16.2	18.0	2.2	-	-	-
	3:30 pm	-	6.2	19.0	3.5	-	-	-
	4:00 pm	-	0.2	21.0	5.5	77	36	-
	4:15 pm	-	-	21.0	5.5	-	-	-
	4:30 pm	-	0.1	22.0	5.6	-	-	-
	5:00 pm	2280	-	23.5	5.8	66	33	4.9×10^5
Jug #4	2:30 pm	9030	35.0	18.0	0.0	85	30	-
	3:00 pm	-	21.0	18.5	0.0	-	-	-
	3:30 pm	-	9.6	20.0	0.7	-	-	-
	4:00 pm	-	0.1	21.0	3.0	79	34	-
	4:15 pm	-	-	21.0	3.8	-	-	-
	4:30 pm	-	0.1	21.3	3.7	-	-	-
	5:00 pm	3900	-	22.5	3.7	68	33	3.0×10^5
Jug #5	2:30 pm	2280	6.0	17.3	6.0	100	74	-
	3:00 pm	-	6.2	18.0	7.6	-	-	-
	3:30 pm	-	10.6	19.0	8.3	-	-	-
	4:00 pm	-	10.4	20.0	8.0	68	46	-
	4:15 pm	-	-	20.0	8.0	-	-	-
	4:30 pm	-	4.6	21.0	8.0	-	-	-
	5:00 pm	2340	3.3	21.5	8.3	-	-	-
	5:30 pm	-	2.2	-	-	-	-	-
	6:00 pm	-	2.6	23.0	8.4	-	-	-
	6:30 pm	-	2.1	-	-	-	-	-
	7:00 pm	-	1.6	21.5	8.5	-	-	-
	8:00 pm	-	0.9	-	-	77	30	1.9×10^5
Jug #6	2:30 pm	2100	5.6	17.5	6.2	100	70	-
	3:00 pm	-	16.0	18.0	5.4	-	-	-
			33.0*					
	3:30 pm	-	31.0	20.0	6.1	-	-	-
	4:00 pm	-	19.6	21.0	6.3	86	67	-
	4:15 pm	-	-	21.0	7.3	-	-	-
	4:30 pm	-	15.0	21.5	7.5	-	-	-
	5:00 pm	2880	12.0	22.5	7.7	-	-	-
	5:30 pm	-	13.0	-	-	-	-	-
	6:00 pm	-	28.5	23.0	8.0	-	-	-
	6:30 pm	-	28.5	-	-	-	-	-
	7:00 pm	-	25.0	23.0	8.2	-	-	-
	8:00 pm	-	27.0	-	-	81	38	2.0×10^5

*Phosphate added as K_2HPO_4 at 3:00 pm.

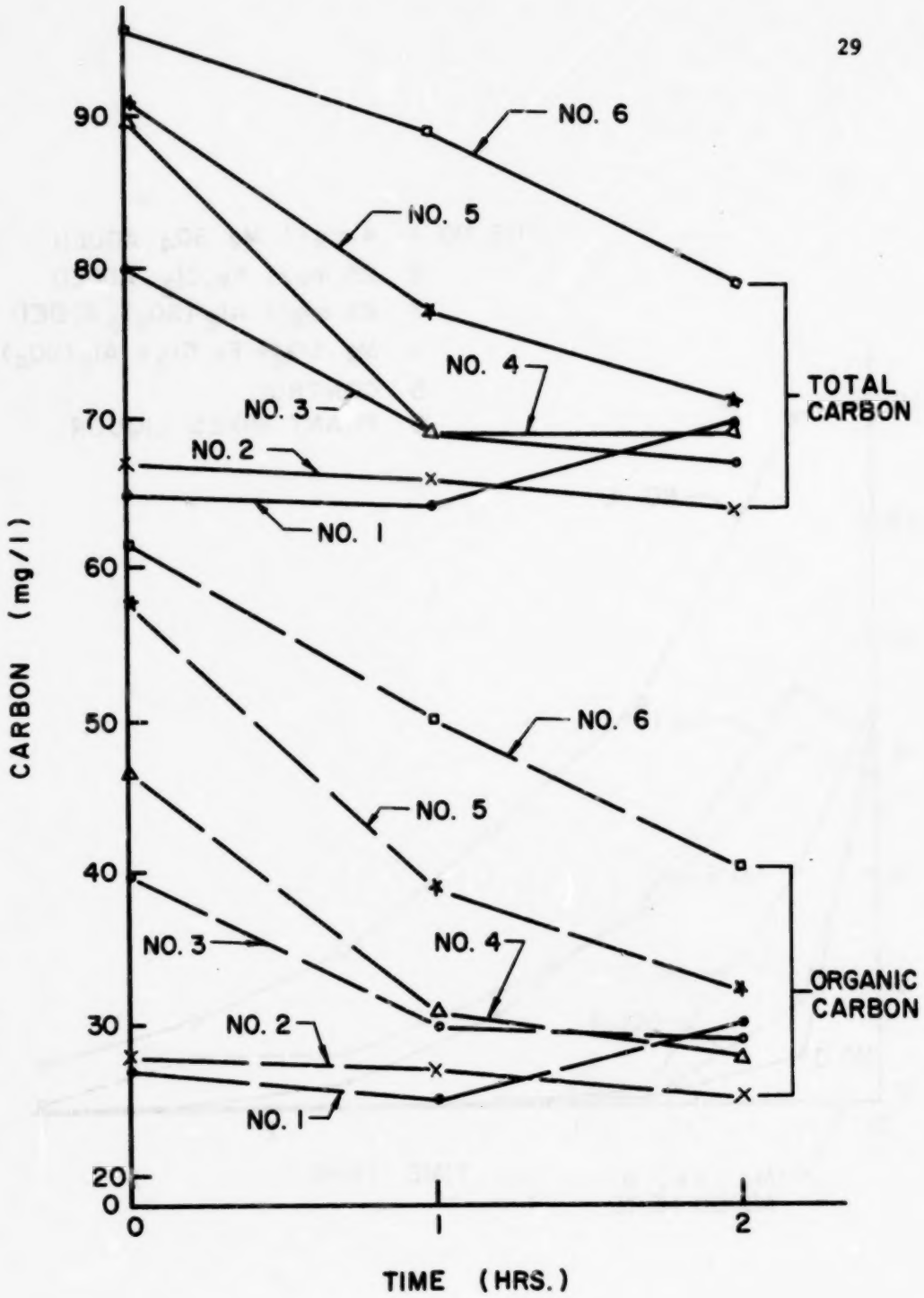

FIGURE NO. 11 — JUG EXPERIMENT NO. 4 : CARBON

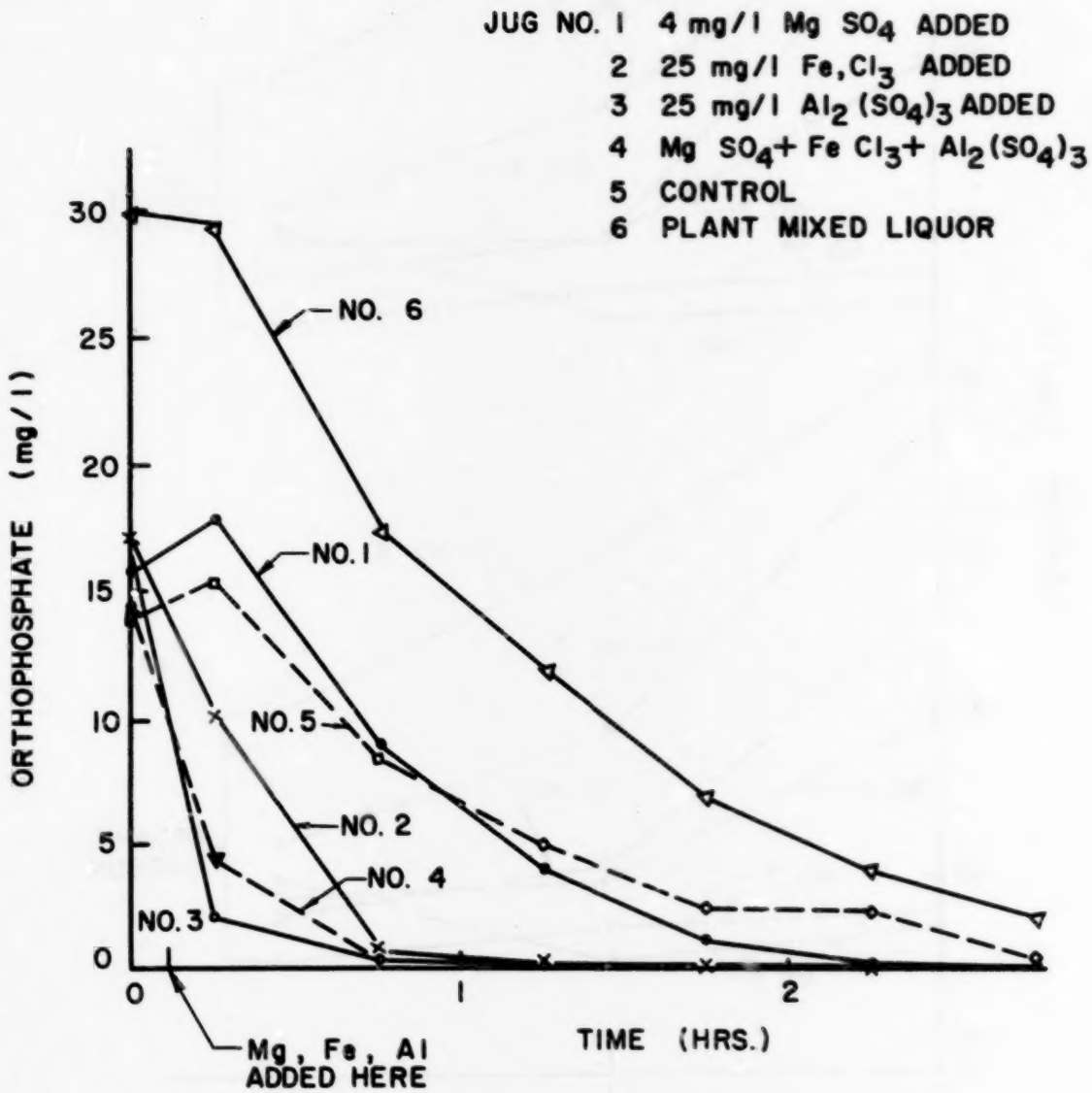

FIGURE NO. 12 – JUG EXPERIMENT NO. 5 : PHOSPHATE

effect with the immediate removal of almost 90 percent of the soluble phosphate. Similar results were obtained by including iron and magnesium with aluminum although the immediate effect was not as great. The addition of 4 mg/l of magnesium sulfate to Jug No. 1 did not produce an immediate phosphate removal although the removal rate was slightly higher than that of the control jug.

These results show that both aluminum and iron are effective precipitates for removal of phosphate and that aluminum produces a greater instantaneous effect than iron. Addition of magnesium produced little if any effect on the removal process.

Jug Experiment No. 6: The first four jugs of this experiment were designed to repeat Jug Experiment No. 2 in which the initial phosphate samples were lost. Jugs Nos. 5 and 6 were used in an attempt to determine the effect of phosphate load on soluble phosphate removal. Jugs Nos. 1 through 4 were prepared simply by holding the primary effluent constant at 10 liters and varying the amount of return sludge from 3 to 20 liters. For Jugs Nos. 3 and 4, it was necessary to concentrate, by flotation, the return sludge from 10 and 20 liters, respectively, down to 5 liters.

In Jugs Nos. 5 and 6, an attempt was made to "strip" the soluble phosphate from the present sludge, thereby preventing phosphate desorption on contact with the primary effluent and reducing the initial soluble phosphate concentrations in the jugs. Ten (10) liters of return sludge were adjusted to a pH of 5.0 by adding sulfuric acid. The sludge was then allowed to set for a one-hour period to permit phosphate desorption. The resulting slurry was then washed twice by sludge flotation to remove the phosphate in the interstitial liquid. The resulting sludge was added to the primary effluent in the jugs.

Figure No. 13 presents phosphate concentrations versus aeration time for the solids variation jugs. These jugs demonstrate essentially the same phosphate characteristics as those in Jug Experiments Nos. 1 and 2. The initial soluble phosphate concentrations increase with increasing MLSS, and all remove greater than 99 percent of this phosphate in 1 1/2 hours of aeration.

The results of the sludge "stripping" operation may be seen in Figure No. 14. Although no measurement was made of the soluble phosphate following the stripping operation, the process was evidently successful in removing the phosphate. The initial phosphate concentrations in Jugs Nos. 5 and 6 were much lower than the concentrations in the primary effluent used to make up the jugs. The stripping operation had a detrimental effect on the phosphate removal properties of the sludge since Jugs Nos. 5 and 6 removed less than 85 and 20 percent, respectively, of the soluble phosphate.

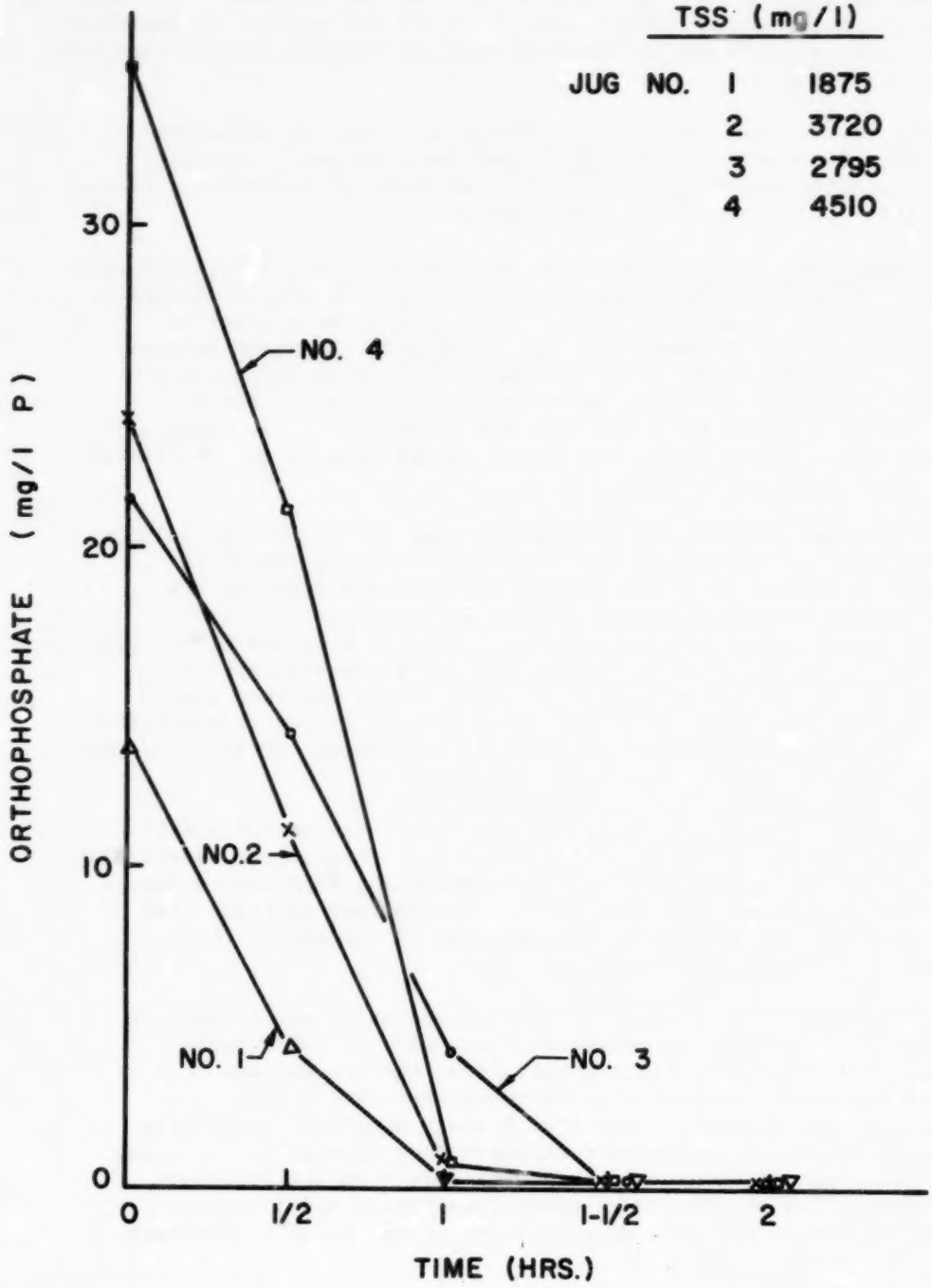

FIGURE NO. 13 — JUG EXPERIMENT NO. 6 : PHOSPHATE

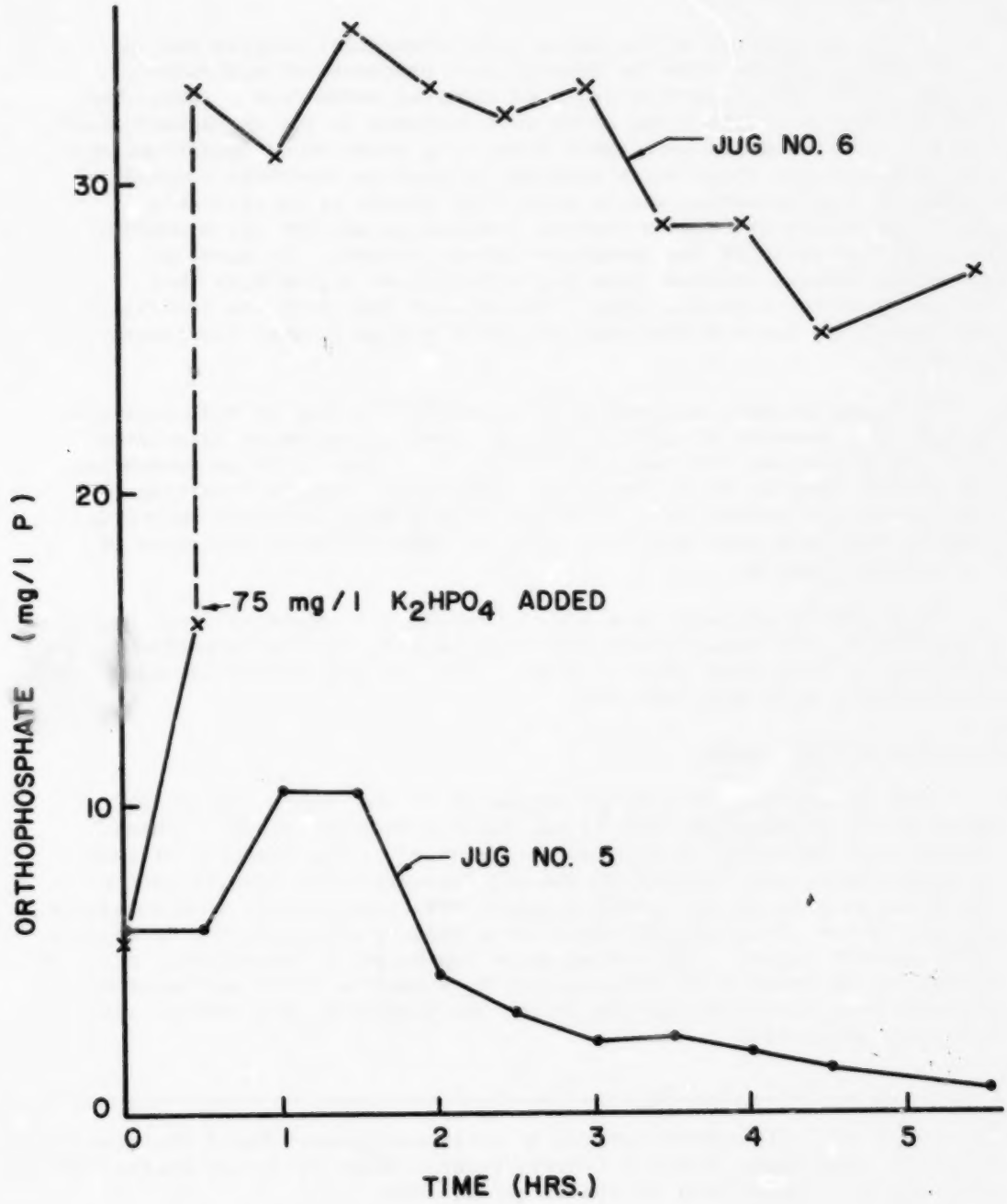

FIGURE NO. 14 — JUG EXPERIMENT NO. 6 : PHOSPHATE

Sewage Characterization

A related purpose of the amenability analytical program was to characterize samples from the various unit processes of activated sludge plants with regard to selected chemical parameters. Additional samples from an aeration jug study were included in the characterization scheme. These samples were taken from a jug study whose operations and constituents were those which resulted in maximum phosphate removal. Primarily, the intention was to search for trends or correlatable functions within or between various chemical parameters which would be useful in defining the phosphate removal process. Frequently, phosphate removal realized from jug aeration was higher than that occurring in the aeration tanks. During such instances the probability of identifying gross differences of possible significance was greatly enhanced.

The samples were analyzed with and without solids to differentiate between the quantity of each respective chemical parameter associated with the solids and that associated with the liquid. Solids separation was accomplished by first decanting, then subjecting the resulting supernatant to further solids removal using a Sharples Ultra centrifuge. Samples resulting from such treatment are referred to as centrates of the original sample.

The samples characterized and the results therefrom will not be discussed in this report since the basic purpose was for comparison with similar data from other studies. Data and comparisons are made and reported under separate cover.[3]

Microbiological Studies

The microbiological studies conducted at the plants tested for amenability to phosphate removal was divided into two phases. Phase I consisted of selection of predominant colonial types, transfer of such to agar slants, and shipment to the Ada laboratory for identification. The final portion of this phase is under way. The results from Baltimore and all of the other amenability studies will be reported at a later date as a separate report. The second phase consisted of determining bacterial number by the total plate count method from various plant and aeration jug samples. A correlation was sought relating phosphate removal with bacterial population.

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[3]Lively, L. D., "Phosphate Removal by Activated Sludge--Waste Characterization," Robert S. Kerr Water Research Center, Federal Water Pollution Control Administration, U. S. Department of the Interior, 1968.

The data from the plate count determinations are recorded in Tables Nos. 2 and 6. There is no apparent relationship between suspended solids content and bacterial contents. The bacterial counts remain essentially constant through the aeration tanks and during the course of the jug runs. From these data, it was concluded that bacterial counts and phosphate removal, if related, were not detectable by the methods employed.

SUMMARY

Studies conducted at the activated sludge plant (Back River Sewage Works) of Baltimore, Maryland, April 3-15, 1967, showed consistent phosphate removals of greater than 90 percent.

Monitoring of the activated sludge plant on 15 different occasions during the 2-week study showed phosphate removals in the aeration tanks as great as 99 percent and on all occasions, except one, greater than 90 percent. The exception was a 40 percent removal on April 7 which was traced directly to a malfunction in one final clarifier, thus allowing sludge to accumulate in the final clarifier for several hours. When the mechanism was repaired, the accumulated sludge was returned as a slug of highly concentrated solids and phosphate. Upon passage of the sludge through the plant, greater than 90 percent phosphate removals were again obtained.

The aeration tanks at Baltimore are very long with a length-width ratio greater than 25:1. Dye tracer studies conducted on these tanks indicated hydraulic conditions approaching plug flow with a modal detention of greater than 90 percent of the displacement time.

The plant operates with mixed liquor suspended solids of about 2,100 mg/l with a 20 percent return sludge rate. About 10 percent of the secondary sludge is wasted. The 1.1 cubic feet of air supplied per gallon of waste treated usually results in 5 or 6 mg/l of dissolved oxygen in the effluent end of the aeration tanks. The dissolved oxygen in the final clarifiers is maintained at about 3 mg/l which accounts for the lack of phosphate bleedback in the final clarifiers. In fact, indications are that some phosphate uptake may be accomplished in the final clarifiers.

Phosphates in the waste stream measured during the study were as follows:

Source	Ortho (mg/l P)		Total (mg/l P)		Average Ratio
	Min.	Max.	Min.	Max.	Ortho/Total
Raw Waste	2.0	8.4	6.0	12.2	0.5
Pri. Eff.	5.3	12.0	10.8	14.0	0.5
Final Eff.	<0.1	0.7	0.6	0.3	0.15

The return sludge was 14 percent PO_4 on a dry weight basis. Soluble phosphate and BOD loadings were 5 lb O-PO_4/day/100 lb MLSS and 46 lb BOD/day/100 lb MLSS, respectively.

Pilot studies were conducted in aerated jugs to determine the effects of various concentrations of MLSS, BOD, phosphate, and of iron, aluminum and magnesium salt additions. A minimum level of MLSS satisfactory for removal was determined. A threefold increase of mixed liquor aeration time was required to remove an initial soluble phosphate content of 120 mg/l P over the typical concentration of 20 to 30 mg/l. The desorption of phosphate from the return sludge to the mixed liquor was increased with the addition of oxygen demanding material. The addition of iron and aluminum salts resulted in an immediate removal of most of the soluble phosphate. The waste and sludge were found amenable to almost complete phosphate uptake under most of the conditions tested.

CONCLUSIONS

1. The activated sludge process at Baltimore Back River Sewage Works obtains extremely high levels of phosphate removal.

2. Both aeration tanks at Baltimore exhibit flow-through characteristics very near plug flow.

3. With the Baltimore aeration tank design, 1.1 cubic foot of air per gallon of (200 mg/1 BOD) waste is sufficient to maintain 5 to 6 mg/1 dissolved oxygen and high levels of phosphate sorption.

4. High dissolved oxygen concentrations in the aeration tank effluent and hence in the final clarifiers prevents desorption of phosphate from sludge solids to final effluent.

5. Excessive sludge detention in the final clarifiers of plants removing phosphate permits extreme phosphate desorption so that the normal air supply and aeration detention time are insufficient to remove the resultant high phosphate concentrations.

6. The activated sludge at Baltimore removes high levels of phosphate at mixed liquor suspended solids between 1,200 and 6,000 mg/1.

7. Under batch conditions, the activated sludge at Baltimore is capable of removing phosphate concentrations greater than 10 times that normally found in wastes.

8. The addition of oxygen demanding substrate to the Baltimore sewage increases the initial desorption of phosphate in the mixed liquor.

9. Increasing levels of initial soluble phosphate lengthen the time of mixed liquor aeration to obtain significant removals.

10. The addition of 25 mg/1 $FeCl_3$ or $Al_2(SO_4)_3$ to the mixed liquor produces an immediate and nearly complete removal of the soluble phosphate.

11. The addition of 4 mg/1 of $MgSO_4$ has little effect on phosphate removal.

12. "Stripping" the available phosphate from the sludge by acidifying and washing greatly inhibits the phosphate removal by the sludge.

13. Aeration of mixed liquor in a jug at a rate between 5 and 10 liters of air per minute per 15 liters of waste provides excellent simulation of phosphate removal in Aeration Tank No. 1 at Baltimore.

RECOMMENDATIONS

This plant is recommended as a full scale research plant to further specify, define, and optimize the parameters of the biological phosphate removal process. Amenability of the waste and sludge at the Baltimore Back River Sewage Works to phosphate removal is conclusive. The plant design is such that a separation could be made at minimum expense, and the aeration tanks and final clarifiers could be operated independently as two distinct parallel secondary systems. This would permit two levels of testing simultaneously or the use of one system as a control while operational parameters such as air supplied, detention time, MLSS, strength of the waste, and others were varied in the other system. Sufficient flow meters are provided.

APPENDIXES

Appendix I

Analytical Procedures

by

B. L. DePrater

A. Sample Preparation

Samples collected for analyses in the field were processed as outlined in the respective analytical test procedures.

Samples returned to the Robert S. Kerr Water Research Center are referred to as whole, centrate, whole fixed, and centrate fixed.

The following table lists the treatment each type received prior to shipment to Ada.

Sample	Treatment
1. Whole	Shipped as is with no treatment.
2. Whole Fixed	Shipped as is plus 1 ml conc sulfuric acid per liter of sample.
3. Centrate	The sample was passed through a Sharples motor driven laboratory model continuous centrifuge, equipped with a clarifier bowl driven at 23,000 rpm. The sample was delivered to the centrifuge by a paristaltic pump at a feed rate of 150 ml/min. The bowl was cleaned and rinsed with distilled water after each sample.
4. Centrate Fixed	The centrate sample plus 1 ml/l conc sulfuric acid.

All samples were shipped in either 250 ml polyethylene bottles or 1,000 ml cubetainers.*

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*Hedwin Corporation, 1600 Roland Heights Avenue, Baltimore, Mayland 21211

B. Chemical Tests

1. Orthophosphate

In the field, initial samples for orthophosphate were filtered immediately using Schleichen and Schuell No. 588 paper. Subsequent analysis by the stannous chloride procedure in Standard Methods[4] included the use of a B&L Spectronic 20 at 690 mμ.

A continuous automatic sampling device, built specifically to support jug-study phosphate analyses, supplied whole samples to a Technicon AutoAnalyzer platformed according to the method by Gales and Julian.[5] The manifold and reagents were modified, however, to more closely approximate Standard Methods.[4] The arrangement, in order of sequence, was as follows:

a. A six-port peristaltic pump circulating jug mixed liquor continuously.

b. An open-shut solenoid valve system selectively sampling the flow from a T-connection in each circulating jug line.

c. A stepping relay alternately activating one of six jug sample solenoids or the solenoid to a distilled wash water supply.

d. A master timer regulating the stepping relay at two-minute intervals.

e. A Technicon proportioning pump providing the flow of samples and distilled water to a Technicon continuous filter. This pump also diluted filtered samples with distilled water in the ratio of 1:40, respectively.

Whole plant samples were run on the Technicon AutoAnalyzer using a Technicon Sampler II and a continuous filter with samples reaching the filter within thirty minutes. No significant orthophosphate bleedback occurred in unfiltered samples during this period.

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[4]Standard Methods for the Examination of Water and Wastewater, 12th Edition, p. 234-236. 1965.

[5]M. E. Gales, Jr., and E. C. Julian, "Determination of Inorganic Phosphate or Total Phosphate in Water by Automatic Analysis." Presented at the 1966 Technicon Symposium on Automation in Analytical Chemistry.

2. Total Phosphate

Analyses were conducted on fixed whole samples at the Ada laboratory within 15 days of sample collection. Initially whole samples were blended for three to five minutes in a Waring blender and then analyzed by the persulfate procedure of Gales and Julian.[5] The procedure was modified to more closely approximate the Standard Methods[4] procedure for orthophosphate in that the samples were neutralized after digestion. Also the manifold design and reagents for the AutoAnalyzer were adjusted to deliver approximately the amount of reagents per sample outlined by Standard Methods.[4]

3. Total Carbon and Total Nonvolatile Organic Carbon

Whole samples were run in the field using the methods of Van Hall, Safranko, and Stenger[6] and Van Hall, Barth, and Stenger.[7] A Beckman Carbonaceous Analyzer was used. Preliminary homogenization with a Waring blender provided representative syringe sampling of whole samples. As the whole acidified sample was further purged with nitrogen gas for five minutes, results were reported as total nonvolatile organic carbon. Acetic acid standards were used for instrument calibration.

4. Total Oxygen Demand

Whole samples were run by the method of Stenger and Van Hall[8] using the instrument and techniques described therein. Preliminary homogenization with a Waring blender was practiced. Sodium acetate standards were used.

5. Total Hardness

In the field, hardness was determined by EDTA titrimetry according to Standard Methods, Method B, p. 147-152.[4]

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[6]C. E. Van Hall, J. Safranko, and V. A. Stenger, "Rapid Combustion Method for the Determination of Organic Substances in Aqueous Solutions," Anal. Chem. 35:3, p. 315-319. 1963.

[7]C. E. Van Hall, D. Barth, and V. A. Stenger, "Elimination of Carbonates from Aqueous Solutions Prior to Organic Carbon Determination," Anal. Chem. 37:6, 769. 1965.

[8]V. A. Stenger and C. E. Van Hall, "Rapid Method for Determination of Chemical Oxygen Demand," Anal. Chem. 39:2, 207. 1967.

6. Chloride

Centrate samples were analyzed for chloride by the method of Hach Chemical Company, p. 13.[9]

C. Physical Tests

1. Solids

Tests for total suspended and total volatile suspended solids were conducted according to Standard Methods[4] (Methods C & D, p. 424-425). Reeve Angel 2.4 cm glass fiber filters grade 934AH were used in lieu of asbestos mats. Gooch crucibles were fired at 600°C, cooled, and the mats placed in the crucibles and dried at 103°C for at least 1 hour before initial weighing. At intervals crucibles with filters were subjected to 600°C furnace temperatures to check for weight loss due to the filter. Total and total volatile solids were determined according to Standard Methods[4] (Methods A & B, p. 423-424).

2. Dissolved Oxygen

Measurements were made in situ with a YSI Model 51 Oxygen Meter equipped with a Model 5103 oxygen/temperature probe. The meter was calibrated against the Azide Modification of the Winkler Method described in Standard Methods[4] (Method A, p. 406-410). The meter was also calibrated against saturated air at the temperature at the test medium.

NOTE: Mention of products and manufacturers is for identification only and does not imply endorsement by the Federal Water Pollution Control Administration or the U. S. Department of the Interior.

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[9]Hach Chemical Company, Ames, Iowa, "Water and Sewage Analysis Procedures," Catalog No. 9. 1966.

Appendix II

Plant Records

Baltimore Back River Plant
Aeration Tank Data

Day 1967	Settl. Sol. (%)	MLSS (mg/l)	Sludge Index	Tot. Air ($ft^3 x10^4$)	Air Rate (ft^3/min)	PE (MG)	Air/Sew (ft^3/gal)
4/1	22.9	2150	106	2218	15138	21.39	1.04
4/2	20.6	1998	103	2086	14486	20.21	1.03
4/3	18.6	1844	101	2063	14326	21.29	0.97
4/4	22.4	2139	105	2274	16242	21.45	1.06
4/5	24.0	2498	96	2267	15743	21.47	1.05
4/6	20.0	2181	91	2205	15312	21.46	1.03
4/7	21.2	2140	99	2349	16312	20.67	1.14
4/8	26.2	2534	104	2340	16250	19.01	1.23
4/9	24.2	2383	102	2319	16104	19.50	1.19
4/10	21.3	2134	100	2230	15486	20.12	1.11
4/11	20.1	2092	96	2331	16188	19.98	1.17
4/12	19.6	2080	94	2459	17076	21.03	1.17
4/13	20.0	2066	97	2364	16417	20.39	1.16
Avg.	21.6	2172	99	2269	15775	20.61	1.10

Day	Suspended Solids (mg/l)				Seconday Sludge ($galx10^3$)			Act. Sl.
1967	FE	C-[1]	C'-[2]	C"-[3]	Tot.Act.	Tot.Ex.	Tot.Ret.	(% solids)
4/1	12.5	140	80	117.1	4645	524	4131	0.914
4/2	-	118	68	91.8	4648	522	4126	0.819
4/3	5.0	155	60	132.0	4481	371	4110	0.858
4/4	5.0	158	73	148.3	4261	156	4105	0.804
4/5	0.0	146	76	140.0	4333	223	4110	0.968
4/6	7.0	145	69	154.8	4617	593	4024	0.842
4/7	11.5	137	65	123.8	4469	503	3966	1.326
4/8	13.0	146	84	133.2	4575	615	3960	0.999
4/9	15.5	107	63	118.8	4609	581	4028	0.919
4/10	2.0	164	82	168.0	4605	501	4104	0.878
4/11	12.0	147	79	157.0	4736	626	4110	0.871
4/12	11.5	176	88	164.0	4835	599	4256	0.847
4/13	15.5	190	90	145.0	4709	648	4061	0.841
Avg.	8.3	148	75	137.9	4578	497	4084	0.914

[1] Primary Effluent Composite Sample Refrigerated
[2] PE Composite After Two Hours Settling
[3] Average of Several PE Grab Samples

Baltimore Back River Plant
TSS and BOD's for March

Date 1967	TSS (mg/l) A[1]	M[2]	C[3]	SE[4]	E[5]	F[6]	BOD (mg/l) A	M	C	SE	E	F
3/1	222	668	136		108	20	226	331	138	9	70	26
3/2	232	-	130		48	22	212	-	195	8	32	26
3/3	204	586	120		98	60	382	352	204	7	62	28
3/8	176	202	166		18	10	212	152	160	8	42	37
3/9*	100	314	82		34	34	176	311	187	8	65	41
3/10*	173	374	172		214	72	212	192	176	7	84	29
3/15*	126	244	112		64	16	122	242	252	12	150	42
3/16*	218	238	144		104	24	247	532	228	5	68	29
3/17*	112	190	130		100	12	197	222	216	7	59	26
3/22*	188	198	162		62	28	311	331	263	27	122	86
3/23*	112	356	178		80	48	231	311	259	21	82	68
3/24*	108	170	86		70	26	207	152	176	10	66	34
3/30*	108	494	158		98	24	157	382	252	13	72	37
3/31*	130	386	120		34	16	192	292	216	6	49	29
Average	158	340	135	13	81	29	220	292	209	11	73	38
Red. (%)			14.6	91.8	48.7	81.6			5.0	95.0	66.8	82.7

* These dates may be in error.
1/ Raw Sewage
2/ Influent to Grit
3/ Primary Effluent to the Activated Sludge Plant
4/ Activated Sludge Final Effluent
5/ Trickling Filter Effluent
6/ Plant Final Effluent

Baltimore Back River Plant
Typical Flow Balance
Friday, September 10, 1966

Time	Metered Inflow MGD	Recirculation MGD	Net Inflow MGD	Metered Flow to BSCO*	Weir Overflow MGD	Total Outflow MGD
1:00 am	154.59	2.84	151.75	119.52	35.9	155.42
2:00 am	145.89		143.05	119.04	39.4	158.44
3:00 am	135.26		132.42	113.04	33.4	146.44
4:00 am	116.91		114.07	96.72	26.0	122.72
5:00 am	97.58		94.74	82.56	21.6	104.16
6:00 am	93.72		90.88	80.40	17.0	97.40
7:00 am	87.92		85.08	87.36	2.2	89.56
8:00 am	98.55		95.71	88.56	2.2	90.76
9:00 am	116.91		114.07	80.16	4.6	84.76
10:00 am	144.91		142.08	129.84	10.3	140.14
11:00 am	160.38		157.54	129.60	15.3	144.90
12:00 N	177.71		174.93	149.52	16.4	165.92
1:00 pm	194.20		191.36	179.52	16.4	185.92
2:00 pm	181.64		178.80	150.24	22.2	172.44
3:00 pm	181.64		178.80	168.52	22.2	190.72
4:00 pm	179.71		176.87	170.40	21.0	191.40
5:00 pm	175.84		173.00	170.88	22.2	193.08
6:00 pm	174.87		172.03	159.36	20.4	179.76
7:00 pm	173.91		171.07	147.60	21.0	168.68
8:00 pm	173.91		171.07	158.64	19.8	178.44
9:00 pm	171.98		169.14	155.76	21.6	177.36
10:00 pm	171.98		169.14	120.96	41.2	162.16
11:00 pm	166.18		163.34	124.56	45.0	169.56
12:00 M	162.31		159.47	118.80	44.1	162.90
Daily Totals	151.61	2.84	148.77	129.23	22.56	151.37

*Bethelem Steel Company

Baltimore Back River Plant
Aeration Tank Data

Date	Time	Aeration Tank 1			Aeration Tank 2		
		PE-TSS (mg/l)	DO (mg/l)	TSS (mg/l)	DO (mg/l)	TSS (mg/l)	Chloride (mg/l)
4/3/67	2:00 am	117	7.1	1896	7.6	1912	85
	6:00 am	103	7.0	1880	6.8	1860	109
	10:00 am	110	7.5	1860	7.5	1820	121
	2:00 pm	138	8.0	1760	8.1	1752	145
	6:00 pm	156	7.5	1744	7.1	1720	133
	10:00 pm	168	6.2	2008	5.4	1916	133
4/4/67	2:00 am	133	4.8	2020	4.2	2024	
	6:00 am	103	5.3	2260	4.5	2040	
	10:00 am	125	5.1	2060	4.5	2000	
	2:00 pm	170	5.1	2160	5.1	2000	
	6:00 pm	155	4.8	2056	5.4	2080	
	10:00 pm	198	5.1	2460	4.3	2488	
4/5/67	2:00 am	150	4.1	2576	4.1	2500	
	6:00 am	115	3.4	2500	3.3	2420	
	10:00 am	120	4.1	2440	4.3	2360	
	2:00 pm	138	5.1	2908	6.0	2412	
	6:00 pm	165	5.2	2596	6.2	2464	
	10:00 pm	152	5.7	2404	5.0	2392	
4/6/67	2:00 am	125	4.2	2384	3.2	2376	
	6:00 am	123	6.1	2240	5.5	2244	
	10:00 am	127	6.2	2048	6.2	2112	
	2:00 pm	214	6.2	2032	6.6	2640	
	6:00 pm	163	6.7	2224	6.7	1928	
	10:00 pm	177	3.9	2020	3.8	1928	
4/7/67	2:00 am	146	4.5	1840	3.9	1912	
	6:00 am	112	5.3	1824	4.1	1756	
	10:00 am	137	6.7	1700	6.6	1708	
	2:00 pm	134	6.6	1680	7.2	1724	
	6:00 pm	123	2.3	3640	1.7	3104	
	10:00 pm	91	5.0	2200	3.3	2600	

Baltimore Back River Plant
Aeration Tank Data
(Continued)

Date	Time	Aeration Tank 1			Aeration Tank 2		
		PE-TSS (mg/1)	DO (mg/1)	TSS (mg/1)	DO (mg/1)	TSS (mg/1)	Chloride (mg/1)
4/10/67	2:00 am	115	6.8	2260	7.4	2092	
	6:00 am	81	6.6	2244	7.5	2164	
	10:00 am	173	7.2	2256	7.3	2056	
	2:00 pm	298	6.9	2068	7.2	1940	
	6:00 pm	212	7.0	2240	6.6	2092	
	10:00 pm	130	6.5	2172	6.2	2020	
4/11/67	2:00 am	143	6.0	2160	5.8	2080	
	6:00 am	96	5.8	2320	5.6	2160	
	10:00 am	95	5.6	1936	5.4	2120	
	2:00 pm	235	6.0	1992	5.7	2004	
	6:00 pm	131	6.2	2064	6.3	2040	
	10:00 pm	140	6.0	2080	6.3	2100	
4/12/67	2:00 am	130	5.9	2140	6.2	2140	
	6:00 am	185	5.6	2216	5.8	2040	
	10:00 am	92	5.4	2280	5.4	2032	
	2:00 pm	255	5.8	2008	5.6	1976	
	6:00 pm	193	5.6	1992	5.8	2040	
	10:00 pm	127	5.7	2052	6.4	2048	
4/13/67	2:00 am	136	5.5	2052	6.2	2056	
	6:00 am	100	3.4	2188	3.4	2140	
	10:00 am	103	3.4	2228	3.0	1960	
	2:00 pm	210	4.1	2012	4.0	2048	
	6:00 pm	178	4.1	2072	4.6	2064	
	10:00 pm	141	6.3	2000	6.0	2052	
4/14/67	2:00 am	175	6.1	2028	5.4	2044	
	6:00 am	121	4.8	2400	4.2	2000	
	10:00 am	98	5.0	2172	5.0	2120	
	2:00 pm		4.3		4.4		

Baltimore Back River Plant
Activated Sludge Plant Data

Date	Time	Aeration Tank 1				Aeration Tank 2			
		Air[1]	Sew[2]	Act[3]	Ret[4]	Air	Sew	Act	Ret
4/3/67	3:00 am	6.6	9.3	2.02	2.38	6.4	11.3	2.30	2.50
	7:00 am	6.6	10.4	2.02	2.38	6.4	11.3	2.32	2.50
	11:00 am	6.3	10.3	2.02	2.38	5.9	11.6	2.32	2.50
	3:00 pm	6.3	10.0	2.02	2.26	6.2	12.0	2.32	2.28
	7:00 pm	6.3	10.2	2.02	2.25	6.7	11.8	2.32	2.29
	11:00 pm	6.4	10.0	2.02	2.25	7.0	11.0	2.31	2.30
4/4/67	3:00 am	6.6	10.0	2.02	2.25	7.3	11.3	2.31	2.30
	7:00 am	6.7	10.8	2.02	2.25	7.3	11.7	2.31	2.28
	11:00 am	6.7	10.6	2.02	2.25	7.3	12.2	2.31	2.28
	3:00 pm	7.0	10.4	2.05	2.24	7.4	11.4	2.31	2.28
	7:00 pm	7.0	10.5	2.05	2.24	7.4	11.5	2.31	2.28
	11:00 pm	7.0	11.0	2.05	2.25	7.4	11.3	2.31	2.26
4/5/67	3:00 am	7.0	10.2	2.03	2.25	7.4	10.7	2.31	2.26
	7:00 am	7.0	10.5	2.03	2.25	7.4	12.0	2.31	2.26
	11:00 am	7.0	10.8	2.02	2.25	7.4	11.0	2.31	2.28
	3:00 pm	7.0	10.5	2.01	2.25	6.9	10.9	2.31	2.28
	7:00 pm	7.0	10.5	2.01	2.25	7.9	11.7	2.31	2.28
	11:00 pm	7.0	10.0	2.00	2.41	7.0	11.9	2.31	2.50
4/6/67	3:00 am	7.0	10.2	2.00	2.40	7.0	11.5	2.31	2.50
	7:00 am	7.0	10.8	2.00	2.40	6.8	11.6	2.31	2.48
	11:00 am	7.9	10.7	2.00	2.40	7.0	11.7	2.31	2.47
	3:00 pm	7.4	10.3	2.00	2.40	6.9	11.3	2.31	2.47
	7:00 pm	7.4	10.3	2.00	2.40	6.8	11.7	2.31	2.48
	11:00 pm	7.4	10.4	2.00	2.40	6.8	11.5	2.31	2.48
4/7/67	3:00 am	7.5	10.0	2.00	2.40	6.7	11.4	2.30	2.42
	7:00 am	7.7	10.8	2.00	2.56	7.2	12.0	2.31	2.46
	11:00 am	7.4	10.0	2.00	2.56	8.0	11.0	2.31	2.46
	3:00 pm	7.6	10.0	2.00	2.58	7.4	10.1	2.31	2.57
	7:00 pm	7.4	9.7	1.88	2.20	7.9	10.6	2.28	2.25
	11:00 pm	7.5	9.7	2.08	2.52	8.1	9.7	2.25	2.45

[1] Total Air (1000 SCFM)
[2] Primary Effluent Flow to Aeration Tanks (MGD)
[3] Return Sludge Pumped to Aeration Tanks (MGD)
[4] Return Sludge From Clarifiers (MGD)

Baltimore Back River Plant
Activated Sludge Plant Data
(Continued)

Date	Time	Aeration Tank 1				Aeration Tank 2			
		Air[1]	Sew[2]	Act[3]	Ret[4]	Air	Sew	Act	Ret
4/10/67	3:00 am	7.0	10.2	2.08	2.48	7.9	11.0	2.28	2.38
	7:00 am	6.9	9.6	2.07	2.46	7.6	10.5	2.25	2.34
	11:00 am	6.9	10.0	2.08	2.48	7.0	10.8	2.25	2.33
	3:00 pm	6.9	10.3	2.08	2.50	7.0	11.0	2.26	2.34
	7:00 pm	7.0	10.2	2.07	2.46	7.4	10.8	2.27	2.48
	11:00 pm	7.2	9.5	2.07	2.48	7.4	10.7	2.27	2.48
4/11/67	3:00 am	7.2	10.0	2.07	2.50	7.8	10.7	2.27	2.48
	7:00 am	7.4	10.2	2.08	2.49	7.9	10.2	2.29	2.48
	11:00 am	7.4	10.3	2.08	2.49	7.7	10.0	2.29	2.43
	3:00 pm	7.3	10.0	2.08	2.49	7.7	10.4	2.28	2.43
	7:00 pm	7.3	10.0	2.08	2.49	7.6	10.7	2.28	2.43
	11:00 pm	7.4	10.0	2.02	2.49	7.8	10.2	2.28	2.43
4/12/67	3:00 am	7.4	10.0	2.04	2.49	8.0	10.2	2.28	2.43
	7:00 am	7.6	10.0	2.02	2.49	8.1	10.3	2.29	2.42
	11:00 am	7.6	10.0	2.02	2.49	7.9	10.9	2.29	2.42
	3:00 pm	7.4	9.9	2.02	2.48	7.8	10.5	2.29	2.43
	7:00 pm	7.4	10.0	2.00	2.45	7.6	11.0	2.28	2.43
	11:00 pm	7.5	9.7	2.00	2.45	7.7	11.1	2.28	2.43
4/13/67	3:00 am	7.5	10.4	-	2.45	7.8	11.0	2.28	2.43
	7:00 am	8.0	9.8	1.96	2.45	7.7	10.9	2.29	2.42
	11:00 am	8.0	10.0	1.92	2.45	7.4	10.7	2.29	2.40
	3:00 pm	8.0	10.1	1.95	2.46	7.4	10.7	2.29	2.41
	7:00 pm	7.9	10.1	1.95	2.45	7.4	11.0	2.29	2.40
	11:00 pm	7.9	9.7	1.95	2.45	7.5	10.8	2.28	2.40
4/14/67	3:00 am	7.9	-	1.96	2.45	7.6	10.9	2.28	2.40
	7:00 am	7.9	9.7	1.98	2.45	7.4	10.0	2.28	2.40
	11:00 am	7.4	9.9	1.98	2.45	7.1	11.1	2.28	2.40
	3:00 pm	7.3	9.8	1.98	2.45	7.1	11.0	2.28	2.40

[1] Total Air (1000 SCFM)
[2] Primary Effluent Flow to Aeration Tanks (MGD)
[3] Return Sludge Pumped to Aeration Tanks (MGD)
[4] Return Sludge From Clarifiers (MGD)

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